Snow-Cover Condition in Japan and Damage of the Sugi (*Cryptomeria Japonica* D. Don)[1]

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Abstract: Japan is one of the most snowiest regions in the world. Particularly the mountainous area of Honshu (the main island), along the Japan Sea has heavy snow in winter. In some places, snow piles up more than four meters and the ground is coverd with snow about one hundred and forty days a year. The sugi tree is widely planted in snowy regions, and snow-pressure damages, such as basal bending, occure in juvenile stands, and after that crown snow-damage, such as stem breakage, happen in younger stands about 10~30 years-old. Basal bending is formed by the difference in recovery rate between the upper part and the lower part of the stem during growing season. Root damage occurs when the stem is prostrated, and the compression wood is formed in the process of the reelection of the fallen stem. Crown snow-damage happens during the condition of comparative warm air temparatures ranged from three degrees below zero to three degrees above zero. The strength of the stem against crown snow-damage depends on the diameter of the tree, tree taper, constunt μ for the root, and the modulus of elasticity. Pulling up the fallen stem, and controlling the tree density are important in preventing these snow damage.

Introduction: It is said that Japan is the snowiest region in the world. The Japan sea area of Honshu has a lot of snow every year. Though the snow protects plants from severe coldness in winter and is an important source of water, it also is the cause of damages such as basal bending and stem breakage. The sugi is an important spicese for reforestation in Japan and the total area of sugi reforestation exceeds 4.15 million ha., making it about 48 percent of the total artifical forest in Japan. The sugi is widely planted in snowy regions, but suffer many kinds of snow damages every year. Basal bending, stem breakage, stem bending and uprooting are recognized problems in the sugi reforestation, and these snow damages are classified in to two types; one is snow-pressure damage which occurs in younger aged trees untill they are about ten-years-old and the other is crown snow-damages which occur in trees over ten years old. But the types of snow damage depends on the snow-cover condition. The author will talk about the relationship between the snow-cover condition in Japan and the type of snow damage, the mechanism of main snow damage and its control.

THE SNOW COVER CONDITION IN JAPAN AND SNOW DAMAGE

The mean annual maximun snow depth of Japan is shown in Fig-1. A high percentage of snowy areas are distributed along the Japan Sea, and in some areas, snow depth exceedes four meters. In contrast there is only about 10~50 centimeters in the area along the Pacific Ocean, and the mountainous area of Shikoku and Kyushu island, and most areas of Shikoku, Kyushu and the southern part of the main island have less than 10 centimeters.

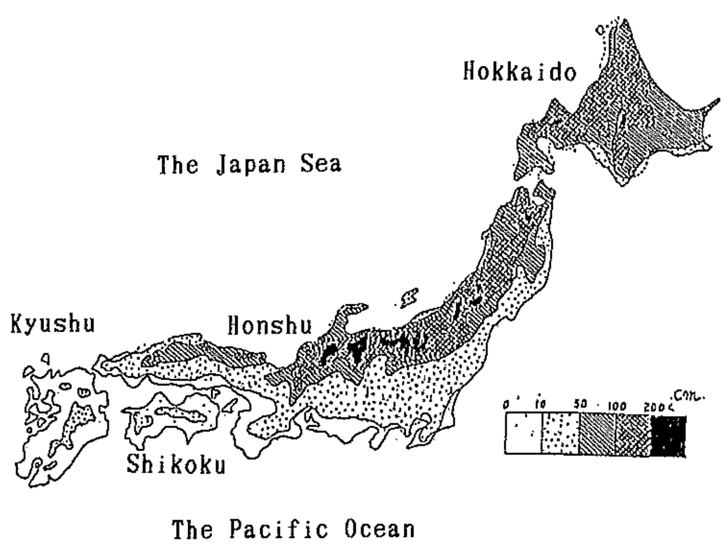

Fig.-1. Distribution map of annual maxmun snow depth

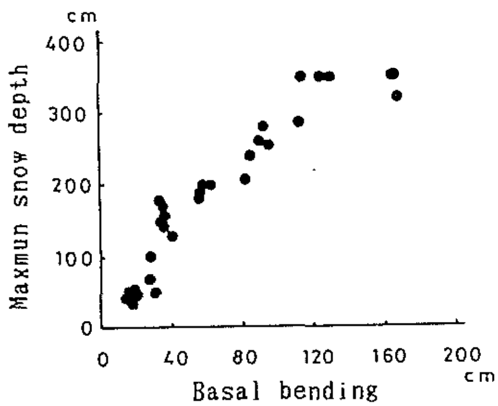

Fig.- 2. The relation between annual maxmun snow depth and basal bending

Quality of snow also varies. There is dry snow in Hokkaido, and the northern and mountainous areas of Honshu, but in the area along the Japan Sea there is wet snow which sticks easily on trees. Snow pails up on the tree crown, and causes stem breakage, which is called crown snow-damage. Also in the Pacific Ocean area of Honshu, crown snow-damage occurs when tropical low pressure passes by the Pacific Ocean and brings wet snow in early spring.

The relationship between basal bending and the mean annual snow depth are shown in Fig-2. Basal bending is about 20 centimeters in the areas where snow depth is below 1 meter. As the snow depth reaches 2 meters, basal bending increase over 60 centimeters, and at depths over 2.5 meters, basal bending increase to 178 centimeters. Basal bending increases as the snow depth increases.

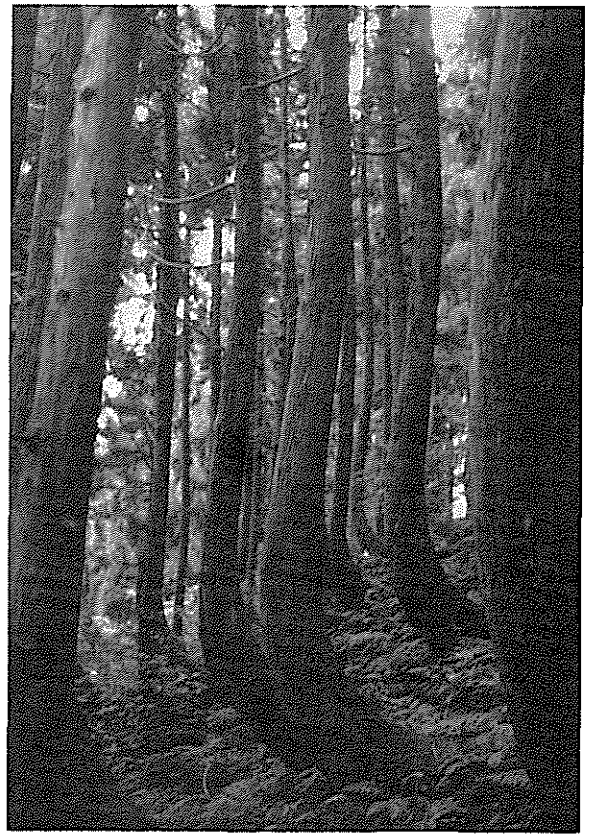

Fig.- 3 Basal bending of cryptomeria

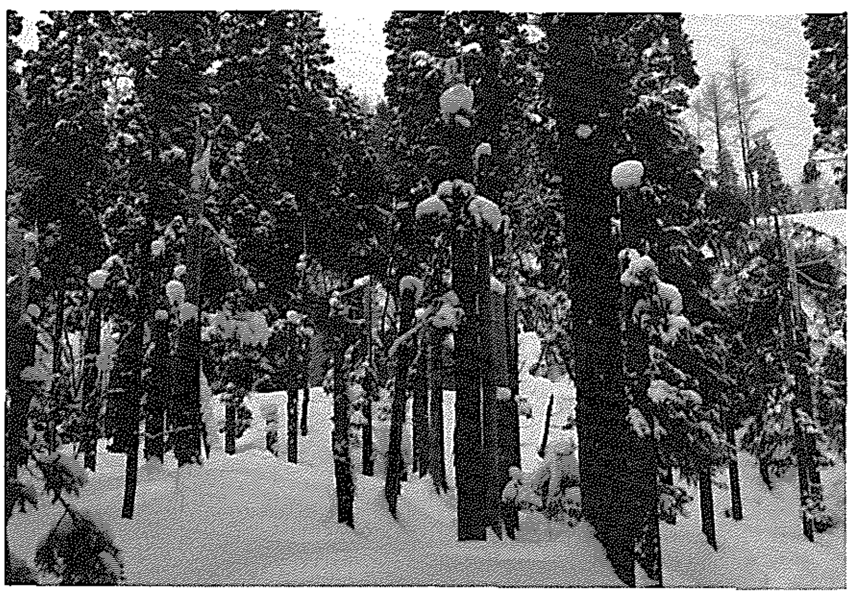

Fig.- 4. Crown snow-damage of cryptomeria

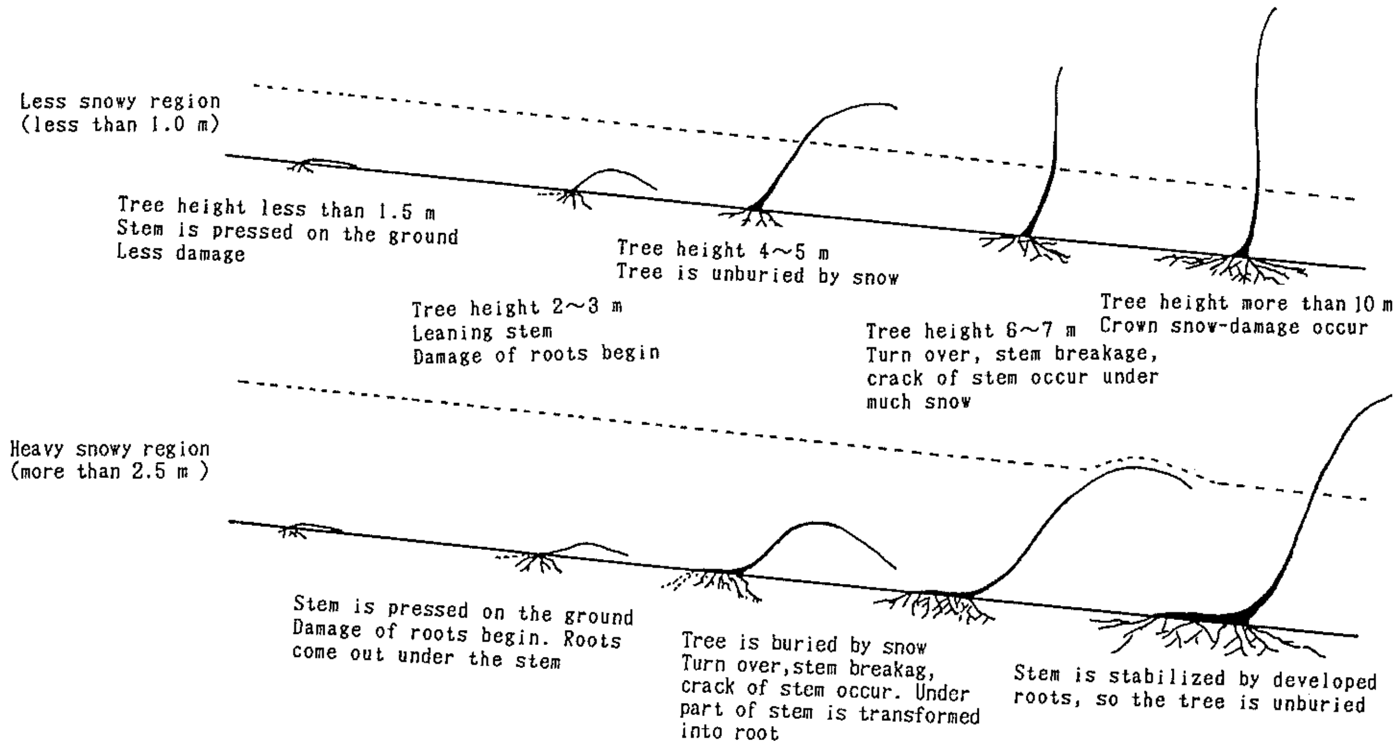

Fig.- 5. Variation of snow damage of cryptomeria by relation between snow depth and tree height

The extent of tree damage varies according to the snow depth and tree height(Fig-5). In areas with snow depths of less than 1.0 meters, only trees less than 2.0～2.5 meters in height are prostrated in winter. Root damage is not serious and stem breakage which becomes fatal seldom occurs. As the tree reaches more than 2.0～2.5 meters in height, the stem does not prostrate with average snow fall depth. However, in heavy snow the possibility of stem breakage and cracking at the bottom of the stem increases and many trees fall and pull out their roots. Snow damage on trees varies from the pulling out of roots to stem breakage (als ocalled crown snow-damage). Crown snow-damage occurs in trees more than 10 meters in height because the stem becomes stiff (and hence, resistant to bending) and the roots are large enough to resist stem prostration. In regions of heavy snow, the young stem repeatedly prostrates and the uprooting of the trees is common. The new roots develop under the part of stem still touching the ground, and the tree then develops resistance against futher prostration. The effects of snow damage during the growing stages rangs from the pulling out of roots to the cracking of the basal stem and stem brakage. In areas with depths of over 2.5 meters of snow, the ratio of dieing trees due to snow damage increases drastically, and it is difficult to forest the sugi in this area.

THE MECHANISUM OF MAIN SNOW DAMAGE

Snow Pressure Damage

The stem of the sugi leans with the initial snow fall and is buried by subsequent snow falls. The snow-covered stem is pressed down by the weight of the accumulated snow and subsequent sedimentation of snow, and is subjected to elastic strain, elastic after-strain and permanent deformation.

In younger trees (one to two years) where stems are soft and thin, the stress is mainly put on the stem and the stem does not lean from the base when the snow press it down on the ground. But,for trees more than three-years-old (height :

1.5~2.0 nmeters), the stem leans from the base because of the increase in its bending stiffness.

In early spring after the release of snow pressure,the stem begins its straightening process with rapid, simple elastic recovery, then elastic after-strain follows. The stem completes its recovery through elastic after-strain until the end of April or early May at which time the stem resumes its recovery with growth and the formation of compression wood. For one-and two-year old trees, stem straigthening is completed by the middle of June or early July; after that, some of the trees increase in weight with tree growth, and this also contributes to the basal bend formation (Fig-6).

Since straightening of the stem with growth is great in one-, two-and three-year-old trees, there is less basal bending on these trees. On the other hand, since straightening of the leaning stem decreases with age, there is greater basal bending in older trees.

The recovery rate observed at each stem positions varies in relationship to the stem's distance from the base. The nearer the stem is to the base, the slower the recovery rate. This difference in recovery rate at various stem positions causes basal bending (Fig-7).

The basal bending of the sugi increases every year. During the early stages of growth, snow depth has no effect on the basal bending of the sugi, but, when the tree attains a height of more than 1.5 meters, increase in snow depth greatly affects stem prostration resulting in greater basal bending. In addition to the two factors mentioned, the slope of the site also affects basal bending. If the snow depth and the height of tree are the same, the amount of stem prostration is affected by the degree of slope. As the slope steepens, the amount of stem prostration increases resulting in greater basal bending.

When the stem is prostrated by snow, the roots suffer damage at the upper part by stretch, at the lower part by pressure, and at the left and right sides by twist. The left and right twisting of the roots, however, does not badly injure them so that they can develop well on both side of the slope. Roots on the down slope side are only slightly damaged due to an increase on the compression force. But roots on the upper slope side are the ones that are severely damaged. They are pulled out,resulting in poor root development.

Therefore, mature bent trees have deformed roots and large side roots (Fig-8). In areas with snow depths of less than 1.0 meters, most of the trees more than 2.5 meters in height are not easily prostrated and the amount of stem prostration is small. Hence, the damage on roots is not so severe and the roots develop normally. In areas of heavy snow, beside root damage and deformation, the lower part of the stem is transformed into roots. When this stem touches the ground due to the weight of snow, roots start to develop from it and the part touching the ground is transformed into a main root.

Roots on both the side and the lower part of the slope are not easily damaged and hence, can develop well. The transformation of the lower part of the stem into a main root increases the resistance of tree against prostration by snow. Morever, the tree is not readily buried in the snow because the transformed main roots effectively prevent stem prostration.

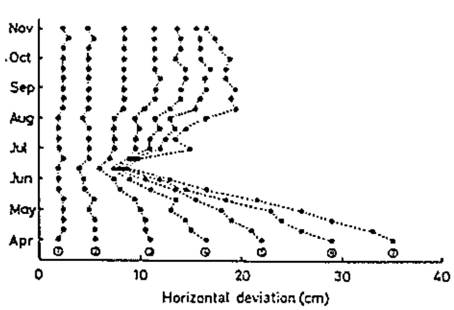

Fig.- 6. Process of straightening of the prostrated stem of a typical 2-year-old tree

① At 5cm above the ground
② 10 〃
③ 20 〃
④ 30 〃
⑤ 40 〃
⑥ 50 〃
⑦ Top

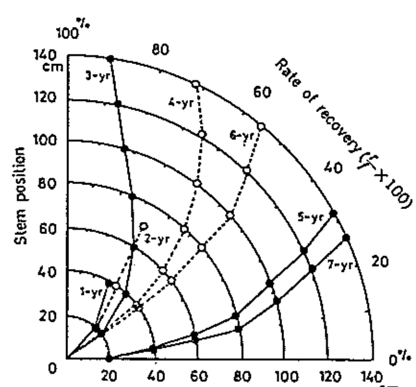

Fig.- 7. Relationship between the deviation from former position (f) and rates of straightening of prostrate stems ((r/f) x 100) at each position during a growing season

Fig.- 8 Deformation of roots

After basal bending is stabilized, surface roots on the down slope develop and the diameter of the lower stem increases towards the down slope. Therefore, the curve of the lower part of the stem is apparently corrected.

Crown Snow-Damage

Snow damage after basal bending has stabilized is called crown snow- damage. It is the phenomena in which the stems are broken by an accelerating snow load on the tree crown. This is roughly classfied into breakage of the stem, breakage of the tip of the stem, and uprooting. Uprooting is the predominant damage among trees less than twenty-years-old, and is sometimes difficult to distinguish from snow pressure damage. Breakage of stem is common in twenty-to thirty-years old stands, and this stand is most sensitive to snow crown damage. In stands More than thirty-years-old, the breakage of the tip of the stem is common, but it is not serious. Also trees with larger stems are more resistant to crown snow-damage than those with smaller stems. But it is difficult to evaluate tree strength against snow crown damage by the shape factor of stem. It is only a comparative standard and it dose not become an absolute one. As mentioned before, crown snow-damages is the phenomena in which the stem is broken by an unendurable snow load, so crown snow-damages can look as if the broken stem is a failure of the tapered column receiving an eccentric compressive load of snow, i.e. the buckeling load (P_{cr}) of stem can be estimated by the following equation.

$$P_{cr} = \sigma^2 \bullet \gamma_s^2 \bullet E \bullet I_o / L^2$$

γ_s^2 : satisties following the equation

$$\tan \gamma / \gamma = -1 / \beta / \alpha - \mu \bullet \gamma^2 \bullet L^2 \bullet I_o / L$$

δ : ratio of taper the stem

β : $1 - \delta$

E : Mudulus in elasticity

L : Height of gravity of a snow-laded crown

I_o : Second moment of cross cection base at the stem

It is understood from the equation that the strengthen against snow crown damage is determined by the diameter of the stem, the taper of the stem, the height of gravity of a snow-load, modulus in elasticity in bending, the μ-index whose value was obtained from the regression coefficient between the turning angle of the tree stem and the turning moment at the stem base. The estimated breaking load is 200~500 kilogram of trees about 20 centimeters at diameter breast height and is agreed with the experimental load which is gotten from broken trees receiving vertical loads as shown Fig-11.

CONTROL METHODS OF MAIN SNOW DAMAGE

Many methods of controlling snow damage have been adapted in the past.Of these control methods, the author will mentioned the most useful ones in this paper.

Snow Pressure Damage

As the cause of basal bending of young trees is stem prostration by snow, pulling up the fallen stem is the most effective method of

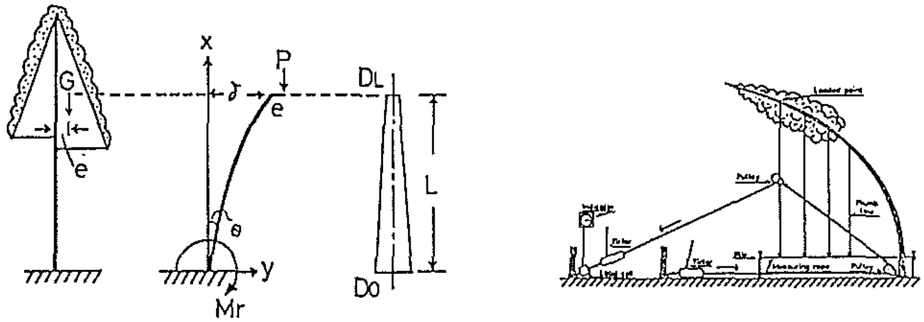

Fig. 11. Diagram of snow-loaded tree and vertical loading test procedure for resistance of tree stem (Nakatani and others, 1984).

Legend: G: the center of gravity of a snow-laden crown, e: horizontal displacement of the center of gravity of the snow-laden crown from the stem axis, P: snow load, θ: turning angle at the stem base, L: height of the center of gravity of the snow-laden crown from the ground, δ: deflection at the height L, D_0: diameter at the stem base, D_L: diameter at the height L.

control. In regions of heavy snow, slant planting which deforms the roots is adaptable because the deformed roots is unsusceptible to stem prostration. Fertizetion increases tree growth, but basal bending also increases at the same time. The degree of basal bending is different largely among the cultivares, so planting of small bend cullivares is an effective way to reduce basal bending. But, it is hard to lean with initial snow, so cultivares with a small degree of basal bending were less frequent in stems leaning under snow, but many stem breakage were observed in heavy snow regions (with snow depths over 1.5 meters).

Crown Snow-Damage

One of the most effective methods for controlling crown snow-damage is to decreas the height/diameter ratio by controlling stand density. The most desirable stand density is 800 ~1200/per hectare at planting, and repeated thinnings are requied when the competition occurs in the stand as the tree grow. Also, as modulus in elasticity in bending is different in the cultivarer, it is important to choose cultivar with large modulus in elasticity in bending for forest owners in the area of much crown snow-damage.

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