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Soft Rot in Utility Poles Salt-treated in the Years 1940–1954

1. Microbiological, microscopic and chemical studies of some salt-treated utility poles installed in Sweden in the years 1941—1946.

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BACKGROUND TO THE INVESTIGATIONS

At the outbreak of the second world war creosote oil was the dominating preservative for utility poles in Sweden. Preservation with salt-preservatives was carried out only to some extent: Boucherie-treatment with copper sulphate and open tank and pressure preservation with preservatives mainly based on fluorides. In 1940 it became more difficult to import creosote oil and later importation stopped completely. The salt-preservatives replaced the creosote oil and efforts to produce a domestic salt-preservative were made. After extensive and forced tests in which comparisons with existing German salt-preservatives of U and UA-type were carried out, the Boliden BIS was introduced. This preservative was then used for all preservation of poles during the war. During a transitional period 1940-1941, however, U and UA-salts were used in addition to the BIS-salt. Moreover, preservation according to the open tank method also took place. One can assume that the quality of the preservative-treated wood during this troublesome period varied considerably. From 1946 the salt-preservation of power line poles decreased successively to the benefit of creosote-preservation. The creosote oil did not succeed, however, in getting back its market for telephone poles. Until 1954 great numbers of utility poles were treated with BIS-salt. After 1952 more effective salt-preservatives took over. *Notice that by salt-treated poles it is here meant utility poles preservative-treated with salt-preservatives in the years 1940-1954.*

Many calculations have been done on the number of BIS-poles that have been installed. No exact figure can be presented but a good estimation is approximately 4 million, of which the main part is still in use. After the accelerated tests in the early 1940s the average service life of the BIS-poles was estimated to be approximately 35 years, a fairly good estimation as shown in results from subsequent investigations (Swed. Wood Pres. Committee: Information om träskydd 1970:1). The reason for this is probably that the poles were over dimensioned at the installation. This means that if the present number of poles are to be kept constant and no preventive measures are taken, 4 million poles must be replaced within 10 years, excluding regular replacements in a group of approximately 10 million poles treated with other preservatives. Such a replacement rate would require a doubling of the present preservation of poles, 200,000-250,000 per year.

To be able to plan the replacement of poles and to guarantee personal safety it is very important to know how to calculate remaining strength of old and decayed poles as well as to predict their remaining service life.

By experience one knows that salt-treated wood in ground contact and in contact with water almost exclusively is attacked by soft rot. This is true for utility poles particularly. Soft rot is caused by a great number of microscopic fungi belonging to the groups *Ascomycetes* and *Fungi imperfecti*. A characteristic feature of genuine soft rot fungi is that their hyphae grow inside the cell walls (S_2 layer) where cavities are formed (Information om träskydd 1969:1). The cellulosic micro fibrils in the wood fibres are decomposed by attack by the enzymes in the hyphae, and the wood quickly loses its strength. In heavily attacked wood the S_2 layer can be completely disintegrated.

Soft rot was observed as early as the middle of the 19th century by the German Schacht (1850, 1863). It was not until 100 years later that the importance of the soft rot fungi as wood destroying agents was discovered. The pioneering work was carried out by the Englishman J.G. Savory who published three important papers in 1954-55. Ever since, the interest for soft rot has been steadily increasing. In Sweden extensive work on soft rot has been done by Lundström and Nilsson who both graduated with their doctor´s degree on soft rot.

The soft rot attacks in salt-treated poles are, excluding poles with backfill of rock, nearly always most severe in a zone just below the ground level. The attacks usually advance from the periphery in towards the heartwood. Quite frequently a more or less apparent difference can be observed between the outer, heavily attacked, soft parts and the relatively hard inner parts. However, it is not unusual that the attacks are quite equally distributed in the sapwood or they may be particularly bad in a certain sector of the pole. Anyway, by conventional methods it is difficult to estimate how far into the wood the attacks are and how developed they are on different depths from the periphery. By help of a microscope it is possible to make such a judgement. It demands, however, that the microscopic observations can be translated into terms of mechanical strength.

In the early 1970s Sydsvenska Kraftaktiebolaget (Sydkraft) started full scale strength tests of poles. It was suspected that the existing inspection methods for salt-treated poles in the case of soft rot were not reliable. Better and more reliable methods must be developed and together with Svenska Reimpregnerings AB Cobra an investigation started on the possibilities for better judging the strength properties of old poles.

Now, full scale strength tests of poles started and in cooperation with the Royal College of Forestry Cobra began regular microscopic examinations of old salt-treated poles. It was soon realized that the problems due to the mechanical strength properties of soft rot attacked wood had to be thoroughly analyzed. The Technical University of Denmark agreed to do such an investigation. Among other things, they had to find a mathematical formula which could be used to transform microscopic results into mechanical terms.

This report consists of four separate papers illustrating different views on the soft rot problem in salt-treated poles. Paper no. 1, written by Björn Henningsson and Thomas Nilsson, is a microbiological, microscopic and chemical investigation of some strength tested salt-treated poles. The investigation was elementary; among other things the preliminary microscopic procedure was worked out. Determinations of fungi in sections from salt-treated poles as well as a chemical analysis of residual components of preservatives in the wood were also done.

The author of paper no. 2 is Preben Hoffmeyer who reports on studies of the relation between compression and tensile strength on one hand and on different degrees of microscopically determined soft rot attacks on the other. By using these relations and known mathematical-physical functions for the strength of poles, a formula for calculating the remaining strength of an attacked pole has been developed.

Henning Friis-Hansen has written paper no. 3. Results from microscopic examinations have been treated by a computer. Different relations are shown for example between the age of a pole, the type of ground and geographical location and the degree of soft rot attack. The rate of development of soft rot attacks in BIS-treated poles has been calculated.

In paper no. 4 by Lars Schmidt and Sven Jacobsson, the results from the full scale strength tests of decayed poles are presented. Indirectly calculated values of the strength are compared to actual values. Finally guidelines for inspection of salt-treated poles are given.

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OBSERVANDUM

This report deals with utility poles treated with water-borne salt preservatives in Sweden in the period 1940-1954. The preservatives used were mainly based on zinc, chromium and arsenic, fluorine and chromium or fluorine, chromium and arsenic. It has to be pointed out very clearly that the effectiveness of these old salt preservatives is much less than that of modern ones. This has been demonstrated repeatedly in many field and laboratory tests. Any transfer of results presented in this report to other types of preservatives will be misleading unless the above statements are considered.

MICROBIOLOGICAL, MICROSCOPIC AND CHEMICAL STUDIES OF SOME SALT-TREATED UTILITY POLES INSTALLED IN SWEDEN IN THE YEARS 1941-1946

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INTRODUCTION

The present report is part of a joint project in which the following persons have contributed in addition to the authors: L Schmidt, S Jacobsson at Sydsvenska Kraftaktiebolaget (Sydkraft), P Hoffmeyer at the Technical University of Denmark, H Friis-Hansen at Svenska Reimpregnerings AB Cobra. The project was initiated when, during strength tests of impregnated utility poles in service, Sydkraft found that currently used methods for pole inspection did not satisfactorily detect existing soft rot. In co-operation with Cobra, further strength tests were initiated and the Royal College of Forestry in Stockholm and the Technical University of Denmark were engaged for the study.

Studies of fundamental problems of microbiological, micromorphological and chemical nature were delegated to the Royal College of Forestry (Department of Forest Products). These studies concerned only a part of Sydkraft's pole material (Schmidt and Jacobsson 1976) and were finished long before the other parts of the joint project. The presented results may therefore sometimes appear rather preliminary in nature. They are, however, described in a detailed way as they often constitute the first steps in the development of methods in the following reports.

It has been known for some time that salt-treated poles from the 1940s are seriously attacked by so-called soft rot (Information om träskydd 1970:1, Henningsson and Nilsson, 1971). Soft rot is described as a particular type of fungal attack on cellulosic fibres. The fungal hyphae grow within the cell wall of the fibre, usually in the S_2-layer. By enzymatic degradation of the cell wall material spiral channels are formed. They are called cavities and can be seen as more or less round holes in a microscopic cross-section of the fibre (see figs 1 and 2).

Attack by soft rot in plant cells was observed and reported in the middle of the 19th century by the German botanist Schacht (1850, 1863). The real importance of the soft rot fungi as wood destroyers was, however, not understood until more than a hundred years later.

The pioneering work was done by the English mycologist J.G. Savory, who published several important papers in the mid-1950s (1954 a, 1954 b and 1955). From that time there has been an increasing interest in soft rot following the accumulation of evidence regarding its destructive effects upon wood. The first alarming report dealing with Swedish conditions appeared as early as 1956 (E Rennerfelt 1956).

The first extensive soft rot attack was discovered in timber in water cooling towers and much of the early research on soft rot concerned such timber. However, it was found that timber in contact with the ground often was severely attacked by soft rot. Organisms able to cause this type of attack were isolated. One of the first fungi causing rapid soft rot was the ascomycete *Chaetomium globosum*. This fungus has since been used to a great extent in laboratory experiments as a prototype of the soft rot fungi. It became, however, more and more evident that a great number of fungi were able to cause soft rot. All these fungi seemed to belong to *Ascomycetes* and *Fungi imperfecti*. Today more than 300 different fungi with the capability of causing soft rot have been recorded (Seehahn, Liese and Kess 1975).

Gradually, research on soft rot problems demonstrated that most of the fungi responsible, in addition to their cavity-forming ability, also caused enzymatic degradation of the wood cell wall from the cell-lumen (Corbett 1965, Nilsson 1973). This degradation appeared as more or less irregular thinning or erosion of the cell wall from the lumen towards the middle lamella. The two types of attack have been named Type 1 (cavities) and Type 2 (erosion).

Investigations soon proved that hardwood (Angiosperms) was less resistant to soft rot than softwood (Gymnosperms). There is, however, insufficient scientific explanation for this difference. It is believed that differences in chemical composition and ultra-structure of the cell walls of the wood fibers are the main causes.

The cavities which result from the Type 1 attack may vary in size and shape. They may be thin and long or wide and short, all depending on fungus species and wood species. The environment may also influence the shape of the cavities (Courtois 1963).

Generally a cavity is initiated by a fungal hypha which penetrates into the cell wall from the cell lumen perpendicular to the fibre-axis. When the hypha reaches the S_2 layer a so-called T-branch is formed. Usually one branch grows upwards and one branch downwards more or less parallell to the fibre-axis. An initial cavity has been formed. When the hyphal branches grow on, they normally closely follow the helical orientation of the cellulose microfibrils forming a chain of cavities divided by very narrow channels (Levy 1965, Lundström 1972). The reason for this special development and orientation of the cavities is under discussion and is the subject of intensive research.

It soon became clear that soft rot fungi could attack preservative-treated timber even if it was obviously well-treated. This was particularly the case for timber in ground contact (Rennerfelt 1956). In recent years severe attack has been observed on the kind of salt-treated pine poles dealt with in the present study (Henningsson, Nilsson 1971). The common factor among these poles is their impregnation with water-borne preservatives which did not contain copper. Field trials and laboratory experiments in the last few decades have clearly shown that copper increases the resistance to soft rot of the treated samples. Today most of the water soluble preservatives for vacuum/pressure impregnation contain copper as one active ingredient.

Field trials, as well as practical experiences (e.g. from Australia) have shown that impregnated hardwood (Angiosperms) in ground contact generally has much less resistance to soft rot than impregnated softwood (Gymnosperms). Not even a careful vacuum/pressure impregnation with an effective preservative to high retentions has given a protection comparable to that of correspondingly treated softwood (Henningsson 1974).

Recent research indicates that the insufficient soft rot protection obtained by impregnation of hardwood may result from an uneven distribution of the preservative within the wood cell wall. By the aid of special electron microscope methods it has been demonstrated that most of the preservative does not penetrate into the S_2 layer in the hardwood fibres. This means that soft rot fungi, which are able to grow in the S_2 layer, can avoid preservatives introduced into the timber by impregnation (Dickinson 1974, Greaves 1974).

MATERIALS AND METHODS

The experimental material in the present part of the joint investigation consisted of 22 sections of transmission line poles impregnated with water-borne preservatives in the years 1941, 1944, 1945 and 1946. Certain poles have been further treated according to the Cobra-method in 1964 or 1971. The sections consisted of the ground-line part from poles, the bending strength of which were tested in the investigations carried out by Sydkraft (Schmidt & Jacobsson 1976). From each pole the two sections above and below the fracture were available (See fig 3).

The diameters of the poles at the position of the fracture were measured by calipering in two opposite directions. Any clean carvings made at the Cobra-treatment were carefully measured and registered.

An attempt was made to estimate the depth of the soft rot attack by the use of a knife. The depth of the attack was measured as close to the fracture as possible on the lower section of the pole and from four diametrically opposite positions. The internal limit of the soft rot attack was considered to be where the wood fibres again broke in a manner characteristic for sound wood undergoing mechanical testing. These measurements were made at two different occasions when the pole sections were relatively dry and later when the sections had been soaked in water for approximately one week.

A quadrant and a boring sample were taken from each pole according to fig 4. They were taken as close as possible to the fracture on the lower piece of the pole section and where the depth of the soft rot attack was estimated to be representative for the pole. The boring sample was prepared before the cutting of the quadrant. An alcohol sterilized borer was used and the work was carried out as sterilely as possible. The borings were placed in sterile glass tubes containing water agar. They were kept in a refrigerator until further treatment.

The borings were then divided into five parts as shown in fig 5. These parts were further cut into smaller pieces which were placed in Petri dishes containing two different substrates - a conventional malt extract agar and a bacteria-toxic agar respectively (Bergman & Nilsson 1971). Growing mycelia were carefully transferred to new agar plates and isolated. An identification of the isolated mycelia was carried out as far as possible.

Each quadrant was cut into an upper three centimeter thick and a lower seven centimeter thick part which were then dried at room temperature. The upper part was used for microscopic studies of the wood and the lower part for chemical analyses.

For the microscopic study samples were taken from four positions along the radius of the quadrant (See fig 6). The sampling positions were located on the following approximate distances from the periphery: A) 5 mm. B) 15 mm, C) half way between B and the heartwood limit and D) 5 mm inside the heartwood limit. The samples were examined with a light microscope in nonpolarized as well as in polarized light. Both earlywood cells and latewood cells were thereby studied in cross-section. Regarding the latewood cells, the soft rot attack was divided into five classes in which the number of cavities at a certain site was used as a criterion:

1. 1 - 10 cavities
2. 10 - 50 cavities
3. 50 - 100 cavities
4. 100 to a state where separate cavities are no longer discernable
5. Complete destruction of the secondary cell walls

This classification system was later replaced by a system with the classes 0 - 4 (see page 2.6). In the earlywood cells where the cell walls are relatively thin, only three classes of soft rot attack were used:

1. Few cavities
2. Several cavities
3. Numerous cavities

In addition to the observations on soft rot cavities the occurrence of brown and white rot was also registered (if possible).

The lower part of the quadrant was divided according to fig 7. Thereby three sapwood layers were separated. These three layers were cut and ground in a laboratory mill to pass a 1 mm sieve. The ground samples were analysed with respect to their content of flourine, arsenic, zinc, chromium, copper and total nitrogen.

The fluorine content was determined using a colorimetric method (Deutsche Normen DIN 52161, March 1967). The method employs the use of eriochromecyanin and zirkonium oxychloride and the determination was made on a spectrophotometer at 525 nm.

Arsenic, zinc, chromium and copper were determined by the use of atomic absorption. The samples were treated in sulphuric acid and hydrogen peroxide according to a method described by the American Wood Preservers Association in their AWPA Standards. After necessary dilutions of the wet combusted samples the measurements were made in an atomic absorption spectrophotometer Techtron AA 120. The values obtained for the various elements were then recalculated to gram per cubic meter. Thereby the basic density of the wood was presupposed to be 500 kg/m^3.

RESULTS AND DISCUSSION

Determinations of the bending strength of the pole using the knife method

Measurements of pole diameter, heartwood diameter and depth of sapwood together with the estimated depth of soft rot are found in table 1. From this table it can be seen that the pole diameters varied between 198 and 260 mm. The material thus consisted of poles with comparatively uniform diameters. If, on the other hand, only the heartwood diameter or the depth of the sapwood is considered, it can easily be seen that these two parameters vary considerably in relation to the pole diameter. The depth of the sapwood varied for example between 25 and 74 mm.

The estimations of the depth of soft rot using the knife method have given several interesting results. Initially it was found that the depth of soft rot attack varied significantly between the poles (from 0 to 29 mm). It was not possible to find a direct correlation between the estimated depth of soft rot attack on one hand and the pole diameter or depth of sapwood on the other. Further, the depth of soft rot attack was found to vary to a great extent in the individual pole. In one case a minimum and maximum depth of 8 and 25 mm respectively was observed. The estimations of the depth of soft rot attack, finally, show that there are significant differences if the poles are dry or wet. In almost every case the registered depth of soft rot was greater in wet poles than in dry.

Using the various measurements of the depth of soft rot attack, maximum, minimum and average bending strengths were calculated for each individual pole. The pole diameter for these calculations was reduced by double the registered depth of the soft rot attack. Thus, the strength of the soft rotted part of the cross section of the pole has been assumed to be 0 (See table 2). The calculated strengths of corresponding sound poles, i.e. if the attacked pole had been sound, are also presented here. The true bending strengths registered at field tests have kindly been supplied by Sydkraft (Schmidt & Jacobsson 1976). These results are introduced in table 2 together with the relative bending strength values calculated on both the strength tests in the field and the estimations made from the knife method (wet pole and minimum bending strength). In the calculations a normal bending strength for sound pine poles of 50 N/mm^2 has been used (SEN 35 0104).

If, using the results in table 2, a comparison is made between the true relative bending strength measured at the strength tests in the field and corresponding strength estimated according to the knife method, they are found to be very similar. A certain overestimation of the bending strength when the knife method has been used can be noticed, however. In a few cases the two values differ significantly. This indicates that the knife method must be refined or that other better methods must be developed if a precise determination of the reduction in strength due to soft rot is required. The slight overestimation of the strength of the poles recorded in table 2 may be due to the fact that the measurements of the depth of soft rot attack could not be made exactly at the fracture site. The fracture zone was often too torn and split to allow such measurements.

Microscopic studies

For the microscopic examinations and the classification of the degree of soft rot mainly soft rot Type 1, cavity formation, was considered. However, soft rot Type 2, erosion, was also observed. In a few cases white rot was also registered. Detailed descriptions of the two types of soft rot attack can be found in publications by Corbett (1965) and Nilsson (1973).

The originally registered five degrees of soft rot were in the following work regrouped into a system of only four classes. This regrouping was done in order to fully harmonize the present study with that by P Hoffmeyer (1976) on soft rot in poles in service. These four degrees of soft rot will then correspond to empirically determined values for the percentage reduction in bending strength (> 30 % moisture content), viz. 23, 45, 67 and 88 % reduction.

In table 1 the degree of soft rot in latewood cells is shown according to both systems. The results show that soft rot attack occurred throughout the whole sapwood in many poles. However, soft rot has not been observed in the heartwood (5 mm from the heartwood limit). A comparison between depth of soft rot attack estimated according to the knife method and the occurrence of soft rot according to microscopic observations clearly shows that rather advanced soft rot may occur deeper in the wood than could be judged from the knife method. That is, certainly one of the reasons for the higher values for bending strength obtained in the calculations compared to the true bending strength values measured at the strength testing in the field. However, the estimation based on the knife method is further complicated since the decayed part of the cross section is regarded as having no residual strength at all. As can be seen in the investigation by Hoffmeyer (1976) 12 and 33 % of the original strength still remained in the poles with degrees of soft rot of 4 and 3, respectively.

If the results from the microscopic examinations are compared with the relative strength values obtained at the field tests and with the calculated strength values for the heartwood (table 2), it is evident that the sapwood even in such heavily attacked poles as no.s 1884-1889 has a significant residual bending strength.

A more detailed examination shows a higher correlation between the microscopic method and the knife method when the soft rot attack is shallow than when deep and extensive attack occurred. In cases of more advanced soft rot attack, simple mechanical means of observation are inadequate for accurate estimation of the depth of decay.

Investigation of the fungus flora in the poles

The isolated fungi are listed in table 3. As is not uncommon in work with heavily contaminated material, there were difficulties in isolating the organisms responsible for the wood decomposition. Although one of the media used contained strong mould- and bacteria-inhibiting components these organisms still completely suppressed others in certain samples.

Of the isolated fungi the following have been proved to cause soft rot in wood: *Acremonium atro-griseum*, *Acremonium* sp., fungus B77 - A23 (described as fungus D by Nilsson 1974), *Phialophora hoffmannii*, *Phialophora fastigiata*, *Phialophora* sp. A, *Rhinocladiella anceps* and fungus SP98-2. Most of these fungi have been found earlier in impregnated timber in ground contact in Sweden (Henningsson & Nilsson 1971, Nilsson 1973 and Nilsson 1974). A few of them have earlier been studied in more detail, e.g. as regards their resistance against various fungitoxic compounds. It was thus shown for example that *Phialophora hoffmannii* and *Phialophora* sp. A are extraordinarily resistant to zinc, arsenic and copper. Zinc as well as copper is included as an active component in the Boliden BIS-salt, with which the poles in the present investigation were once impregnated.

If the poles are grouped with reference to ground line treatment (Cobra-treatment) it is found that from poles lacking such treatment (574 - 7745) or from poles treated prior to 1964 (1884 - 1889) soft rot fungi were isolated in abundance. Samples from poles no.s 1886, 574 and 1744 are exceptions which were heavily contaminated with bacteria and moulds. No soft rot fungi could be isolated from poles which were Cobra-treated in 1971. From pole no. 891 no micro-organisms at all were isolated. This indicates that by the Cobra-treatment a temporary sterilization is produced, the effects of which remain for at least one year. Nine years after the treatment no effects on the composition of the fungus flora were observed.

An interesting observation is that soft rot fungi have been isolated from the heartwood. (7619:5, 7624:5, 7625:5). However, the microscopic examination could not reveal any attack on the fibre cell walls. This indicates that hypha from soft rot fungi had already penetrated into the heartwood in certain poles although enzymatic degradation of the wood had not yet started. Soft rot in the heartwood of BIS-treated timber in ground contact has been reported earlier (Henningsson & Nilsson 1971).

It can be concluded regarding the occurrence of fungi that active, qualified soft rot fungi were generally present in the sapwood of the studied poles. Poles recently Cobra-treated (1971) were the only exceptions.

Chemical analyses of the content of fluorine, arsenic, zinc, chromium, copper and total nitrogen in the wood

As has been pointed out, the poles in this study were most probably vacuum/pressure impregnated with Boliden BIS-salt. This preservative was used for practically all impregnation of poles in Sweden during the Second World War and, to a significant degree, also in the years immediately after the war. The BIS-salt had the following composition: $3H_3AsO_4 + 2Na_2HAsO_4 + Na_2Cr_2O_7 + 3ZnSO_4$. During the preparation of the impregnation solution the zinc sulphate and the remaining part of the preservative were dissolved separately before the two solutions were mixed together. The final solution mixture contained 1.5 % of the zinc sulphate solution and 2.0 % of the arsenic-chromate solution. If it is assumed that pine (*Pinus silvestris*) sapwood absorbs approximately 600 l impregnation solution per cubic metre, then a well treated BIS-pole should have had a retention of 21 kg of the preservative per cubic metre sapwood. This corresponds to about 4 kg arsenic, 1 kg chromium and 2 kg zinc per m^3.

The results of the chemical analyses are shown in table 4 and fig 8. It can be seen that the contents of the components supplied at the original preservation treatment vary consistently in the three sapwood layers. The highest amounts are found in the outer layer and the lowest in the innermost layer. Such a gradient in preservative content is found also in recently impregnated timber. The average values for the pole group B (574 - 7745), i.e. those which have not been Cobra-treated, indicate that during the service period of the poles arsenic was subject to the highest and chromium to the lowest leaching. The observations between the individual poles may partly be due to differences in leaching conditions (moisture content and pH of the soil, rainfall etc.). However, substantial differences probably existed from the beginning due to differences in the impregnation.

The leaching of preservative from the poles not Cobra-treated was on an expected level.

The leaching trials which were once carried out on BIS-treated timber showed that approximately 65 % of the arsenic was leachable (Rennerfelt 1946). The result of the microbiological examination has clearly shown that residual amounts of arsenic and zinc have been too low to prevent soft rot attack. There are even reasons to assume that the toxic effect against certain soft rot fungi was insufficient long before the leaching had reached its present level.

The analyses of pole group A (1884 - 1889), i.e. the poles which were Cobra-treated in 1964, show that the content of arsenic as well as zinc and chromium was significantly lower than for the other poles. The greatest difference is found for the content of zinc, which for these poles was 20-30 times lower than for the other poles, whereas the arsenic and chromium contents were 2-3 times lower. The reason for these large differences has no satisfactory explanation at present. One explanation could be that the preservative used was not correctly balanced as regards the composition and that the original retention therefore was very low. Another explanation could be that these poles were not vacuum/pressure treated but treated by an open tank method. Such treatments were occasionally used in south and central Sweden in the beginning of the 1940s. A third explanation could be that the BIS-salt was not used for these poles. Preservatives of CFA-type were still used to some extent. Mixtures of different preservatives may also have been in use.

The fluorine analyses show that all the poles which have been Cobra-treated also contain fluorine in amounts varying from 0.174 to 1.322 kg/m^3 sapwood. If the various sapwood layers are compared in poles treated in 1964 and 1971 it is found that the fluorine content is high in the outer parts shortly after the Cobra-treatment. Thereafter a migration of fluorides evidently takes place inwards into the pole as well as out into the surrounding soil. One year after Cobra-treatment approximately 1 kg fluorine per m^3 could be found in the outer layer whereas only 0.3 kg/m^3 could be found after 9 years. A content of around 1 kg/m^3 of active fluorine (ion-form) is regarded as necessary for a reasonable protection against decay fungi (Liese and Gröger 1954). The microbiological analysis also shows that the residual amount of fluorine nine years after the treatment was not sufficient to prevent growth of soft rot fungi. At that time the fungus flora in Cobra-treated and untreated poles was nearly identical.

The copper analyses verify that the poles were treated with a copper-free salt. Only in one case have significant copper contents been registered. There is at present no explanation for the relatively high copper content in this pole (7621). Other minor quantities of copper in the outer layer of certain poles probably originated from the surrounding soil.

Finally, the nitrogen analyses show slightly higher nitrogen content in the outer layers of Cobra-treated poles compared to other poles. This can result from dinitrophenols in the Cobra preservative. The values for the nitrogen content further indicate that the poles have received significant amounts of nitrogen compounds from the surrounding soil. Normally fresh sapwood of pine contains less than 0.4 kg N per m^3. The increased nitrogen content may well have an accelerating effect on the development of the soft rot attack. It is known from several studies (c.f. Duncan 1960 and Lundström 1973) that an additional supply of nitrogen to wood will increase the rate of attack of most known soft rot fungi. It has also been shown recently that addition of nitrogen compounds to a substrate may increase the toxic limit to copper and arsenic for several wood destroying fungi (Henningsson 1976).

SUMMARY

A number of sections from the fracture region of strength tested poles was studied. The poles were impregnated and had been in service for 25-30 years.

Using microscopic examinations of the extent and distribution of soft rot and a mechanical method (knife) for estimation of the depth of soft rot, calculations were made to determine the residual bending strength of the poles. The results were compared with those obtained by strength testing. Usually the residual strength estimate was slightly too high compared with the true strength. Under the microscope, soft rot could

be demonstrated deeper in the pole than was estimated by the knife method.

The knife method gave a significantly more accurate result in wet than in dry poles.

The examination of the fungus flora revealed the presence of a number of soft rot fungi in almost all the poles. *Phialophora hoffmannii, Phialophora sp. A, Rhinocladiella anceps* and *Acremonium atro-griseum* were commonly found.

Cobra-treatment caused a sterilization of the poles, which was still effective one year after the treatment. Nine years after treatment, however, no difference in fungus flora was detectable between Cobra-treated and nontreated poles.

Chemical analyses showed the following order of leachability among the elements originally used in the preservative: arsenic > zinc > chromium. The residual amounts of arsenic and zinc were not high enough to protect the wood from attack by soft rot fungi.

The fluorine analyses showed that in recently Cobra-treated poles the concentration of fluorine was very high in the outermost layers (more than 1 kg/m^3). In poles Cobra-treated nine years before the testing, a migration had taken place, resulting in lower concentrations and a more uniform distribution of fluorine in the various layers.

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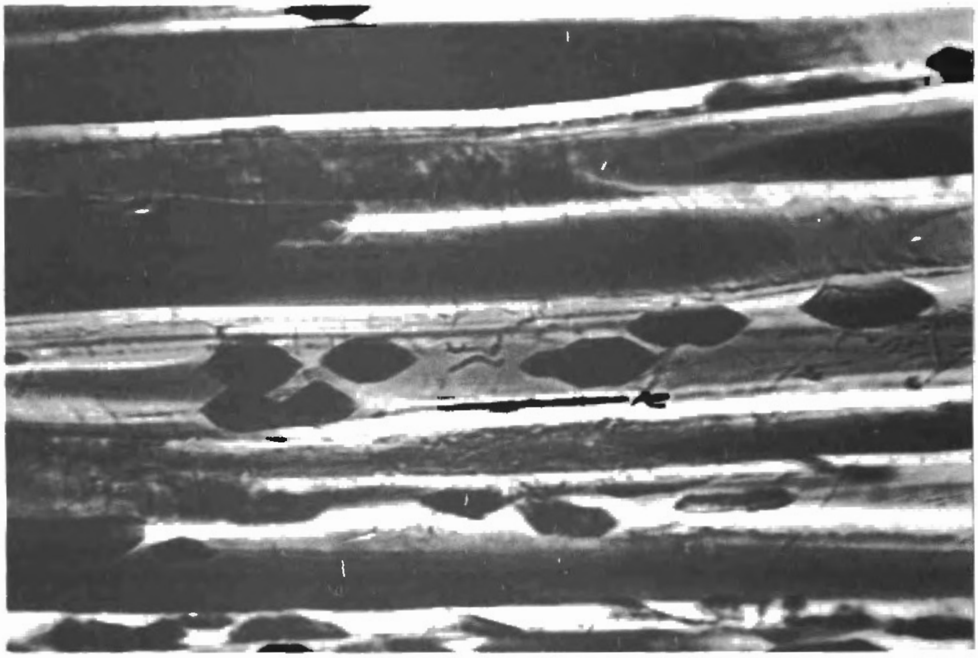

Fig 1. Longitudinal section of birch wood (*Betula verrucosa Ehrh.*) showing typical soft rot cavities. Approx. 650x.
Photo Thomas Nilsson 1973

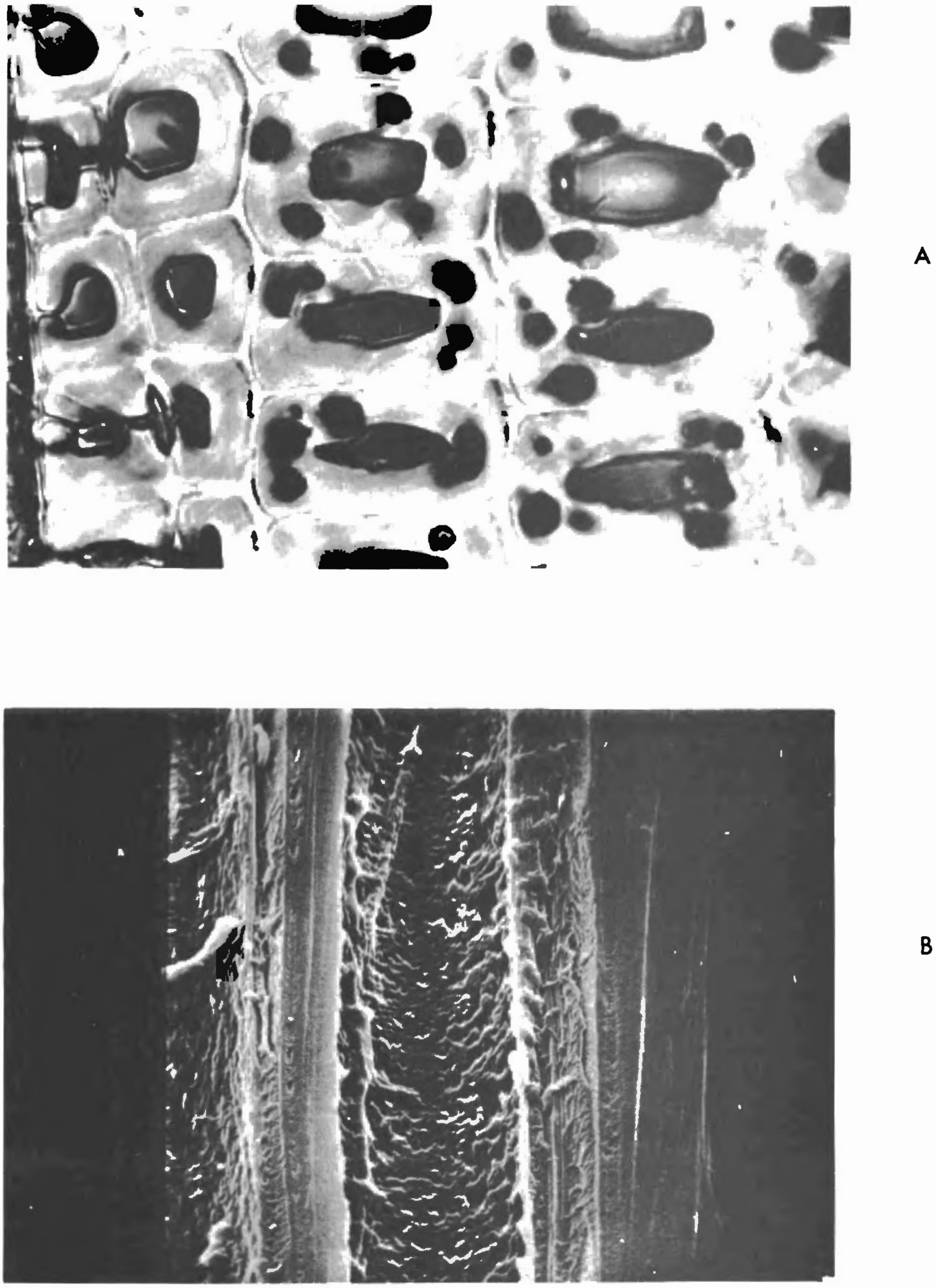

Fig 2 a. Transverse section of pine wood (*Pinus silvestris L.*) showing characteristic Type 1 attack. Approx. 900x.

b. Scanning electron micrograph of a longitudinal section of birch (*Betula verrucosa Ehrh.*) showing characteristic Type 2 attack. Approx. 2,100x
From T. Nilsson 1973

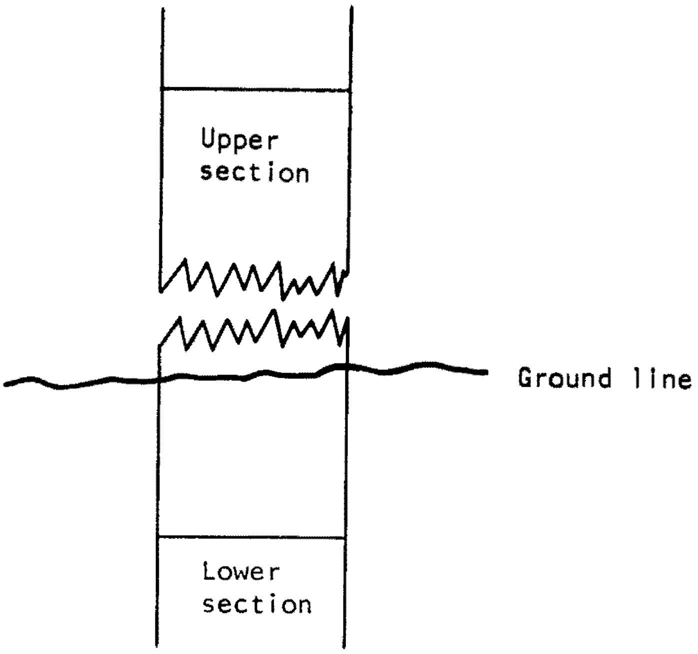

Fig 3. The study included the two pole sections on either side of the fracture.

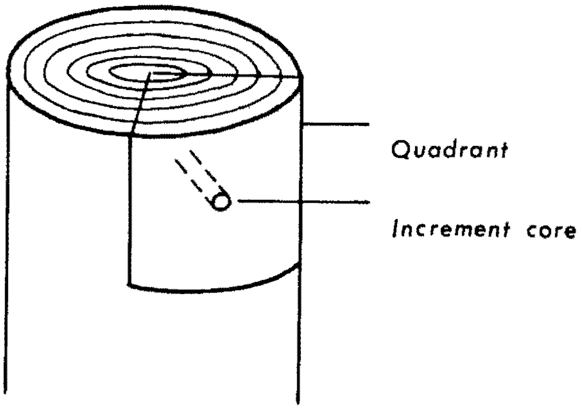

Fig 4. After a careful cleaning of the surface of the fracture, an increment core and a quadrant were taken from each pole.

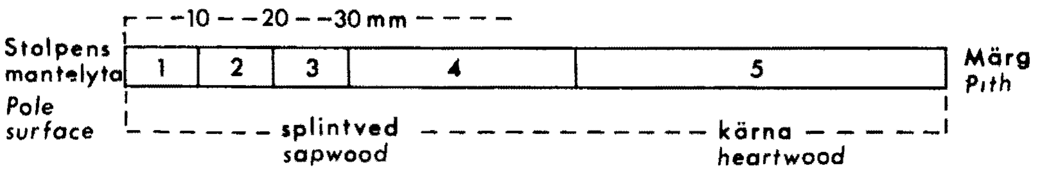

Fig 5. The increment core was sectioned in five pieces when the microbiological analysis was prepared.

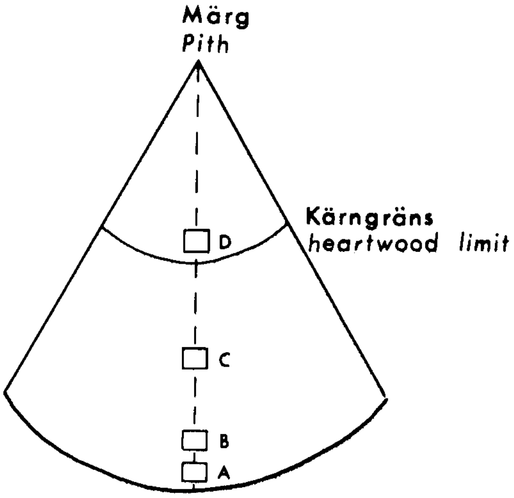

Fig 6. For the microscopic studies four samples were taken from each quadrant on the following positions: 5 (A) and 15 (B) mm from the periphery respectively, and half the distance between position (B) and the heartwood limit (C) and finally, approximately 5 mm inside the heartwood limit (D).

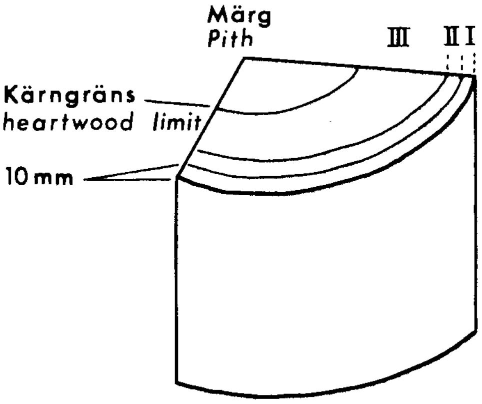

Fig 7. For the chemical analyses the sapwood of the quadrant was divided into three layers. The depth of the outer two layers (I and II) was 10 mm. The inner layer contained the remaining part of the sapwood.

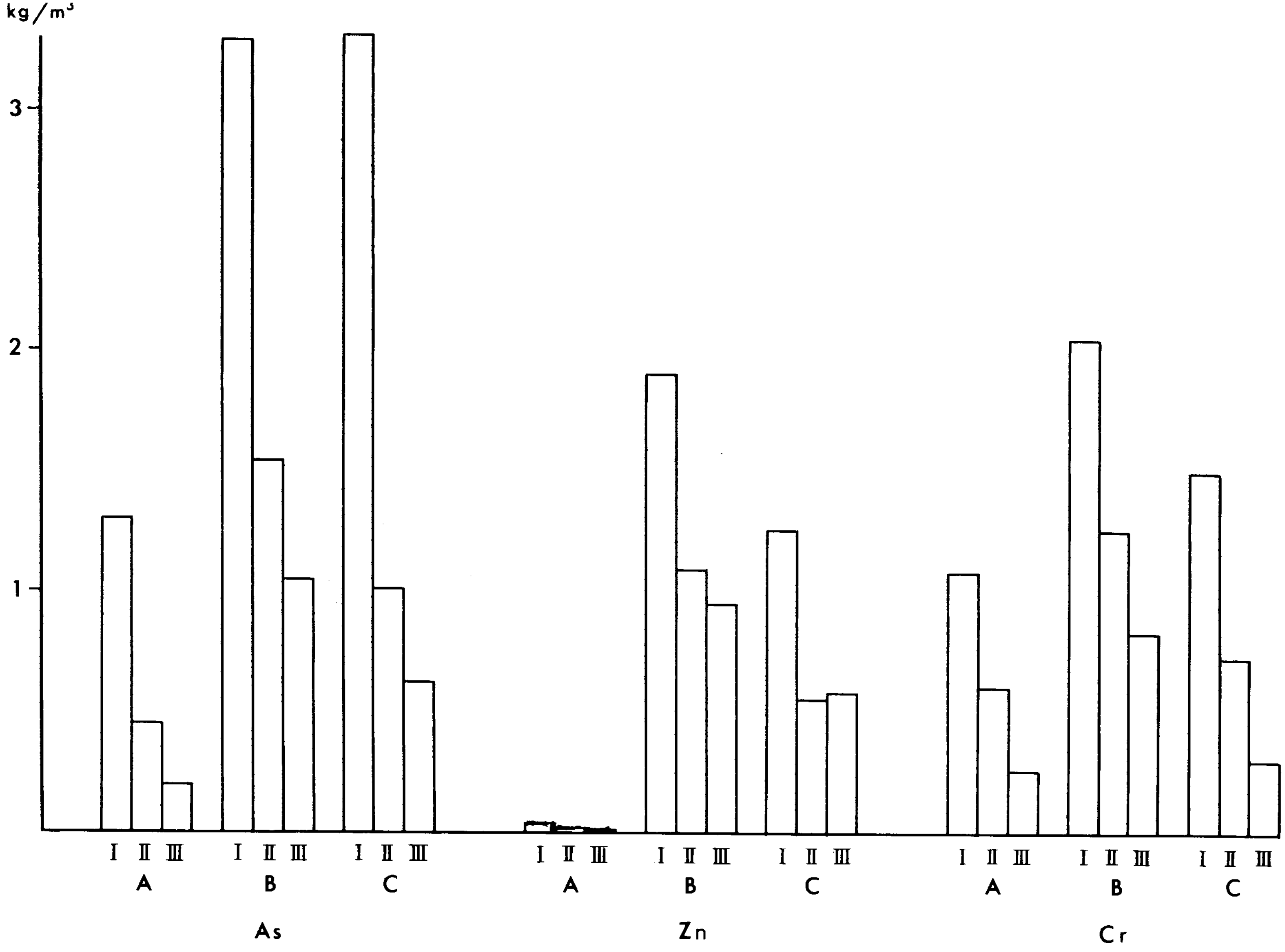

Fig 8. Diagram showing the content of arsenic, zinc, and chromium in the outer (I), middle (II) and inner (III) layers in poles Cobra-treated in 1964 (A) and 1971 (C) and poles not Cobra-treated (B).

Pole no.	Diameter		Depth of sapwood	Depth of soft rot (mm) determined according to the knife method		Degree of soft rot in latewood tracheids determined by microscopy									
	Pole mm	Heartwood mm	mm	Dry samples	Wet samples	A (5 mm from the periphery)		B (15 mm from the periphery)		C (x mm from the periphery)			D Heartwood (y mm from the periphery)		
						4	5	4	5	4	5	x	4	5	y
1884	210	110	50	11 (9-14)	13 (9-19)	3	4	3	4	3	4	(33)	0	0	(55)
1885	234	100	67	22 (17-27)	21 (15-25)	4	5	3	4	3	4	(41)	0	0	(72))
1886	231	120	55	9 (5-17)	27 (22-30)	4	5	3	4	3	4	(35)	0	0	(60)
1887	229	100	65	9 (6-16)	29 (25-30)	4	5	3	4	3	4	(40)	0	0	(70)
1889	201	105	48	17 (15-21)	18 (12-22)	3	4	3	4	3	4	(32)	0	0	(53)
574	226	125	50	0 (0)	1	0	0	0	0	0	0	(33)	0	0	(55)
584	230	120	55	3 (0-7)	4 (3-5)	2	3	1	2	1	1	(35)	0	0	(60)
596	205	155	25	5 (4-7)	7 (6-8)	4	5	3	4	3	4				
597	249	110	70	8 (2-13)	18 (15-20)	3	4	3	4	3	4	(43)	0	0	(75)
3332	231	120	55	4 (2-6)	8 (5-10)	3	4	2	3	2	3	(35)	0	0	(60)
7618	215	110	50	2 (0-4)	6 (2-15)	3	4	1	1	1	1	(33)	0	0	(55)
7619	221	105	58	5 (0-11)	7 (6-9)	3	4	2	3	2	3	(37)	0	0	(63)
7620	218	130	44	5 (3-7)	13 (10-15)	3	4	3	4	3	4	(30)	0	0	(49)
7621	209	155	27	0 (0)	11 (8-15)	3	4	2	3	1	2	(21)	0	0	(32)
7623	206	150	28	7 (5-9)	14 (11-20)	4	5	3	4	0	0	(22)	0	0	(33)
7624	260	170	45	4 (2-5)	8 (3-10)	3	4	3	4	1	2	(30)	0	0	(50)
7625	234	145	45	6 (2-10)	4 (2-5)	3	4 WR	1	2	1	2	(30)	0	0	(50)
7742	235	165	35	8 (6-10)	15 (9-24)	3	4	3	4	2	3	(25)	0	0	(40)
7744	198	100	49	10 (8-15)	18 (15-20)	3	4	2	3	2	3	(32)	0	0	(54)
7745	208	120	44	8 (5-11)	17 (8-25)	3	4	2	3	3	4	(30)	0	0	(49)
889	232	100	66	7 (6-8)	7 (5-8)	3	4	2	3 WR	1	1	(41)	0	0	(71)
891	243	95	74	0 (0)	5 (1-9)	2	3	1	1	1	1	(45)	0	0	(79)

Table 1. Registered parameters for the poles (diameter, heartwood diameter, depth of sapwood), depth of soft rot decay in dry and wet poles according to the knife method and the degree of soft rot in latewood tracheids on various distances from the pole periphery as determined by microscope. Figures within brackets for depth of soft rot indicate the variation. Figures within brackets for microscopy show the exact position of the sample in mm from pole surface. WR = white rot.

Pole no.	Bending strength, kN									Relative bending strength, %		Difference in relative bending strength
	Sound pole		Soft rot decayed pole									
	Entire pole	Heartwood	According to the knife method						Registered at strength test in the field	Registered at strength test in the field	Calculated according to the knife method x)	
			Dry pole			Wet pole						
			Min	Average	Max	Min	Average	Max		I	II	II - I
1884	6.0	0.85	3.7	4.3	4.5	3.3	4.0	4.5	2.3	38	55	18
1885	7.8	0.63	3.6	4.3	5.0	3.9	4.4	5.3	2.4	31	50	19
1886	6.9	1.1	4.9	6.2	6.9	3.2	3.6	4.2	2.0	29	46	17
1887	6.7	0.63	4.7	5.8	6.3	3.0	3.1	3.5	2.5	37	45	8
1889	5.2	0.75	2.6	3.0	3.2	2.3	2.9	3.6	1.8	35	44	9
574	6.4	1.1	-	6.4	-	-	6.3	-	5.5	85	98	13
584	6.0	0.91	5.3	5.9	6.2	5.6	5.7	5.9	3.8	75	93	18
596	4.2	2.0	3.7	3.9	4.1	3.6	3.7	3.8	2.8	67	86	19
597	8.1	0.79	6.6	7.5	8.7	5.4	5.7	6.2	2.5	31	67	36
3332	6.5	1.1	6.4	6.8	7.1	5.7	6.1	6.6	4.1	63	88	25
7618	6.6	0.81	6.2	6.6	6.9	4.4	5.8	6.6	5.3	80	67	-13
7619	5.6	0.70	4.7	5.7	6.5	5.0	5.3	5.5	2.8	50	89	39
7620	6.8	1.4	5.5	5.8	6.1	4.3	4.5	5.8	3.2	47	63	16
7621	6.5	2.3	-	5.6	-	3.5	4.0	4.4	3.6	55	54	-1
7623	7.0	2.3	5.0	5.3	5.7	3.4	4.2	4.7	3.5	50	49	-1
7624	10.0	3.2	10.0	10.3	10.8	8.9	9.3	10.5	3.8	38	89	51
7625	8.6	1.9	6.0	6.7	7.4	6.9	7.0	7.4	5.5	65	80	15
7742	7.6	2.8	6.1	6.5	6.8	4.0	5.3	6.3	3.8	50	53	3
7744	4.6	0.62	2.9	3.5	3.7	2.4	2.6	2.9	2.5	54	52	-2
7745	5.7	1.1	3.9	4.3	4.7	2.4	3.2	4.3	3.0	53	42	-11
889	7.2	0.57	5.8	5.9	6.1	5.8	5.9	6.3	2.8	39	81	42
891	7.4	0.49	-	8.2	-	6.5	7.3	8.0	4.3	57	88	31

x) Wet pole, minimum calculated bending strength

Table 2. Theoretically calculated and absolutely registered bending strength in kN and relative bending strength of the soft rot decayed poles in per cent of the theoretically calculated bending strength of the sound poles.

Table 3. Isolated and identified fungi. Sample no. 1, 2, and 3 consist of first, second, and third centimeter of the sapwood. Sample no. 5 is taken from the heartwood and sample no. 4 from the remaining part of the sapwood. In some poles the sapwood was too narrow to allow the samples 4 and 3 to be taken. The underlined fungi have been shown to cause soft rot (Nilsson 1973).

Sample no.	Isolated micro-organisms
1884:1	Acremonium atro-griseum, Penicillium sp
2	Acremonium atro-griseum, Penicillium sp
3	Penicillium sp
4	Penicillium sp
5	Penicillium sp
1885:1	Phialophora hoffmannii
2	Phialophora hoffmannii, Penicillium sp
3	Acremonium atro-griseum, Penicillium sp, bacteria
4	Penicillium sp
5	sterile
1886:1	Trichoderma sp, Penicillium sp
2	Trichoderma sp
3	Trichoderma sp
4	Trichoderma sp
5	Trichoderma sp
1887:1	white rot fungus, Penicillium sp, bacteria
2	Phialophora hoffmannii
3	Phialophora hoffmannii
5	sterile
1889:1	Acremonium atro-griseum
2	Acremonium atro-griseum, Phialophora fastigiata, bacteria
5	bacteria
574:1	bacteria
2	bacteria
3	bacteria
4	bacteria
5	bacteria
584:1	fungus B77-A-23
2	fungus B77-A-23
3	fungus B77-A-23
4	Cladosporium sp
5	sterile
596:1	sterile
2	Phialophora sp A (former Phialocephala sp)
5	sterile
597:1	sterile
2	sterile
3	Phialophora sp A (former Phialocephala sp)
4	Phialophora sp A
3332:1	sterile
2	sterile
3	fungus B77-A-23, Penicillium sp
5	Penicillium sp
7618:1	Penicillium sp
2	fungus B77-A-23, penicillium sp
3	fungus B77-A-23, penicillium sp
4	Penicillium sp
5	Penicillium sp
7619:1	sterile
2	sterile
3	fungus B77-A-23
4	Penicillium sp
5	fungus B77-A-23
7620:1	bacteria
2	fungus SP100-1 (brown-black mycelium), bacteria
3	Rhinocladiella mansonii, Rhinocladiella anceps, bacteria
4	Penicillium sp
5	Penicillium sp
7621:1	fungus B77-A-23
2	fungus B77-A-23
5	sterile
7623:1	sterile
2	sterile
3	Phialophora sp A (former Phialocephala sp)
5	Penicillium sp
7624:1	fungus SP100-1
2	fungus SP100-1
3	fungus SP100-1
5	Rhinocladiella anceps, bacteria
7625:1	fungus B77-A-23
2	fungus B77-A-23
3	fungus B77-A-23
4	fungus B77-A-23, soft rot fungus SP98-2
5	fungus B77-A-23
7742:1	sterile
2	Acremonium sp, fungus B77-A-23
3	Rhinocladiella mansonii
D	sterile
7744:1	Penicillium sp
2	Penicillium sp
3	Penicillium sp
4	Penicillium sp
5	Penicillium sp
7745:1	sterile
2	sterile
3	Phialophora sp A,(former Phialocephala sp)
5	sterile
889:1	sterile
2	sterile
3	sterile
4	Penicillium sp
5	Penicillium sp
891:1	sterile
2	sterile
3	sterile
5	sterile

Table 4. Results from the chemical analyses. The average values for each group of poles have been calculated.
A = poles Cobra-treated in 1964, B = poles not Cobra-treated and C = poles Cobra-treated in 1971.
x) = detection limit of used method of analysis.

Sample no.	Layer	Content, kg/m³ sapwood											Preservative-treated, year	Cobra-treated, year
		F x) min. 0.013	M̄	As	M̄	Zn	M̄	Cr	M̄	Cu x) min. 0.01	N	M̄		
1884	I	0.347	0.314	1.04	0.54	0.087	0.096	1.26	0.75	0.068	0.98	0.55	1941	1964
	II	0.269		0.42		0.021		0.74		0	0.38			
	III	0.327		0.17		0.018		0.25		0	0.30			
1885	I	0.324	0.308	1.20	0.59	0.033	0.021	1.11	0.72	0	0.10	0.38	1941	1964
	II	0.358		0.47		0.019		0.77		0	0.67			
	III	0.242		0.11		0.012		0.30		0	0.37			
1886	I	0.203	0.329	1.35	0.57	0.039	0.027	0.59	0.45	0	0.99	0.67	1941	1964
	II	0.322		0.25		0.023		0.45		0	0.58			
	III	0.462		0.12		0.020		0.31		0	0.46			
1887	I	0.416	0.314	0.21	0.34	0.069	0.032	1.65	0.81	0	1.31	0.64	1941	1964
	II	0.262		0.56		0.017		0.56		0	0.39			
	III	0.264		0.25		0.011		0.22		0	0.24			
1889	I	0.212	0.235	1.69	0.83	0.082	0.036	0.77	0.49	0	1.01	0.58	1941	1964
	II	0.175		0.53		0.017		0.50		0	0.42			
	III	0.320		0.29		0.009		0.21		0	0.33			
M̄ 1884 Ⓐ 1889	I	0.300	0.300	1.30	0.64	0.062	0.031	1.08	0.65		1.08	0.63	1941	1964
	II	0.277		0.45		0.019		0.60			0.49			
	III	0.323		0.19		0.014		0.26			0.34			
574	I	0		3.59	1.71	1.89	1.77	1.64	1.13	0	0.37	0.27	1944	-
	II	0		3.21		2.34		0.60		0	0.23			
	III	0		1.33		1.08		0.60		0	0.23			
584	I	0		3.15	2.22	1.81	1.49	1.86	1.29	0	0.49	0.33	1944	-
	II	0		2.15		1.47		1.24		0	0.27			
	III	0		1.37		1.20		0.77		0	0.23			
596	I	0		1.69	0.27	0.89	0.48	1.85	1.06	0	1.03	0.69	1964	-
	II	0		0.54		0.56		0.27		0	0.35			
	III	0												
597	I	0		8.43	3.65	5.78	2.42	1.91	1.28	0.021	0.68	0.44	1944	-
	II	0		1.84		0.83		1.43		0.012	0.39			
	III	0		0.68		0.67		0.50		0	0.25			
3332	I	0		1.72	0.88	2.03	1.42	1.30	0.76	0	0.24	0.36	1946	-
	II	0		0.68		1.34		0.73		0	0.24			
	III	0		0.26		0.90		0.26		0	0.26			
7618	I	0		2.69	2.06	1.59	1.45	1.74	1.30	0.014	0.48	0.29	1946	-
	II	0		1.72		1.32		1.11		0	0.22			
	III	0		1.78		1.44		1.06		0	0.18			
7619	I	0		2.87	1.93	1.61	1.34	2.40	1.79	0.012	0.76	0.42	1946	-
	II	0		1.52		1.12		1.64		0	0.27			
	III	0		1.41		1.30		1.33		0	0.25			
7620	I	0		3.33	2.31	1.48	1.39	2.31	1.49	0	0.89	0.57	1946	-
	II	0		1.93		1.33		1.20		0	0.41			
	III	0		1.69		1.38		0.96		0	0.41			
7621	I	0		3.32	1.70	1.45	1.15	2.58	1.23	0.414	0.98	0.52	1946	-
	II	0		0.99		0.55		0.73		0.040	0.34			
	III	0		0.80		0.45		0.40		0	0.26			
7623	I	0		3.61	1.92	1.61	1.14	2.12	1.18	0	0.64	0.38	1945	-
	II	0		1.54		1.12		1.01		0	0.26			
	III	0		0.63		0.71		0.43		0	0.24			
7624	I	0		5.10	2.89	3.68	1.94	2.45	1.69	0.013	0.81	0.48	1945	-
	II	0		2.07		1.18		1.50		0	0.33			
	III	0		1.52		0.98		1.14		0	0.30			
7625	I	0		2.23	1.17	1.24	0.84	1.62	0.84	0	0.63	0.35	1946	-
	II	0		1.05		0.82		0.79		0	0.24			
	III	0		0.24		0.47		0.11		0	0.19			
7742	I	0		2.53	1.75	1.06	0.99	1.85	1.08	0.051	1.38	0.77	1946	-
	II	0		1.65		0.98		0.86		0	0.61			
	III	0		1.09		0.93		0.53		0	0.32			
7744	I	0		2.42	1.37	1.62	1.03	2.10	1.12	0.079	1.62	0.72	1946	-
	II	0		1.02		0.75		0.83		0	0.35			
	III	0		0.67		0.73		0.43		0	0.19			
7745	I	0		2.63	1.71	0.84	0.84	3.01	1.85	0.111	1.38	0.70	1946	-
	II	0		1.21		0.69		1.44		0	0.49			
	III	0		1.29		1.00		1.10		0	0.25			
M̄ 574 Ⓑ 7745	I	0		3.29	1.96	1.91	1.31	2.05	1.36		0.85		1944 ↓ 1946	
	II	0		1.54		1.09		1.26			0.33			
	III	0		1.05		0.95		0.78			0.25			
889	I	0.921	0.443	2.08	1.00	1.13	0.69	1.46	0.69	0.025	0.80	0.47	1946	1971
	II	0.234		0.68		0.51		0.51		0	0.35			
	III	0.174		0.26		0.43		0.11		0	0.27			
891	I	1.322	0.652	5.05	2.45	1.39	0.90	1.52		0.054	1.19	0.60	1946	1971
	II	0.345		1.33		0.60		0.92		0.021	0.36			
	III	0.291		0.97		0.72		0.47		0	0.25			
M̄ 889 Ⓒ 891	I	1.122	0.548	3.57	1.73	1.26	0.80	1.49	0.83		1.00	0.54	1946	1971
	II	0.290		1.01		0.56		0.72			0.36			
	III	0.233		0.62		0.58		0.29			0.26			

2

MECHANICAL PROPERTIES OF SOFT ROT DECAYED SCOTS PINE WITH SPECIAL REFERENCE TO WOODEN POLES

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CONTENTS

1. ABSTRACT

Small, clear specimens from 0.6 metre long ground level bolts of 17 soft rot attacked Scots pine poles are tested in compression and tension. The poles were salt impregnated and had been in service for 25 - 30 years. The poles were sampled at different locations in Southern Sweden. Strength data and elasticity data representing two levels of moisture content are expressed as functions of weight loss and degree of soft rot decay. Sorption isotherms for varying soft rot decay are presented. Scanning electron micrographs illustrating the tensile failure mechanism of soft rot decayed wood are presented. A simplified method of calculating the strength of a soft rot decayed transmission pole is proposed.

2. SCOPE AND BACKGROUND

Though 20 years have elapsed since soft rot was recognized as an economically important wood destroying factor, only limited work has been done in order to determine the effect of soft rot attack on the strength and elasticity properties of wood.

Most work has dealt with strength properties more as a tool for evaluating the degree of fungal attack rather than as a means of predicting the load bearing capacity of the decayed wood element. No work has been done concerning the influence of soft rot attack on the elastic properties of wood.

This is surprising because very important load-bearing wooden elements (telephone poles, power pylons etc.) have been known for a number of years to be subjected to severe soft rot attack.

The present work represents an attempt to clarify in some detail the correlation between soft rot attack and the strength and elastic properties in tension and compression of Scots pine *(Pinus silvestris)* with a special reference to salt-impregnated wooden poles. The work is part of a joint project(x) on soft rot and has been started as a result of the field tests of Sydkraft (Schmidt and Jacobsson 1976). The present work was initiated and supported by Svenska Reimpregnerings AB Cobra and carried out at the Technical University of Denmark.

3. INTRODUCTION

Certain fungi of the groups *Ascomycetes* and *Fungi imperfecti* have a preferred habitat in the central part of the secondary layer of a wood cell wall (Figs 1 and 2). This type of cell wall decomposition was observed microscopically and attributed to fungus action by

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Schact as early as 1863. It was not until the early 1950's, however, that Savory and Findlay, in their pioneering work on the deterioration of timber slats in water cooling towers, described this type of fungal attack in some detail and at the same time recognized its economic importance (Savory 1954a, 1954b; Findlay and Savory 1954). Savory coined the term "soft rot" as he observed a typical softening in the surface layers of the rotting wood.

During the past 20 years much knowledge has been added, and today several hundred species causing soft rot have been isolated and identified from sources ranging from sunken ships to railway sleepers, telephone poles, power pylons etc. Extensive reviews of various soft rot aspects have been given by Levy (1965), Liese (1970), Wilcox (1973), Lundström (1974b), and Nilsson (1974d). A short review of soft rot aspects important to the question of alteration of the mechanical properties of attacked softwood is presented below.

Soft rot fungi are reported to derive nourishment from holocelluloses in general and cellulose in particular. Though the ability to use lignin as a nutrient is questioned, there seems to be no doubt that certain soft rot fungi can deplete lignin (Savory and Pinion, 1958; Levi and Preston 1965, Seifert 1966). Savory and Pinion (1958) measured changes in constituents of beech during decay of *Chaetomium globosum* and concluded that as the early removal of cell wall constituents corresponds closely to the gross chemical composition of the central part of the S_2 layer, lignin is metabolized too. Levi and Preston (1965), also using *Chaetomium globosum* on beech, disagree and suggest that lignin is only modified and left as a network which is easily mechanically compressed or easily collapses. The authors' conclusion is partly based on evidence from transmission electron micrographs.

Nilsson (1974c) showed that certain soft rot fungi degrade lignified substrates more readily than non-lignified.

The enzymes of soft rot hyphae cause a removal of wood substance in the immediate vicinity of the hyphae only (Liese, 1965; Levy 1965). A limited diffusion and action of the enzymes may also take place outside the cavities (Cowling, 1961; Liese, 1965; Levi and Preston,

1965) resulting in a long distance chemical alteration of the cell wall substance.

The cellulose concentration of a cell wall has a maximum, and the lignin concentration a minimum, in the central part of the S_2 layer. As, furthermore, the major part of the increase of total cell wall thickness from springwood to latewood is due to an increase of the S_2 layer, this suggests why a soft rot attack is initiated very often in the S_2 cell walls of the last few latewood rows of an annual ring.

Fig. 1 shows a diagram of cell wall organization including typical soft rot cavities in the S_2 layer. This layer, having a high cellulose content and a microfibrillar orientation almost parallel to the fiber axis, is the real strength element of the cell. Cavity formation consequently causes a drop in most strength and elastic properties to develop more rapidly than would be expected from the mere decrease in dry wood specific gravity.

An additional drop, especially in tensile, static and impact bending strength, may be caused by the long distance depolymerization as mentioned above and possibly by a dissolution of chemical and physical bonds between lignin and carbohydrates similar to what has been suggested for brown and white rot by Henningsson (1967).

Recently, Nilsson (1974e) demonstrated the presence of a diffusible cellulolytic factor in brown rotted wood, which caused reduction in tensile strength of cotton bands attached to the wood blocks. Only very little microscopically visible degradation was seen in the cotton fibres, and Nilsson suggests that "the degradation was limited to a certain splitting of the cellulose chains".

Liese and Pechmann (1959) report a 50 % decrease of impact bending strength for a 5 % reduction of weight. Armstrong and Savory's (1959) results on beech (*Fagus sylvatica)* showed similarly for a 5 % weight reduction a decrease of impact bending strength and static bending strength of 60 % and 18 %, respectively. Others, like Zenker (1962), Zycha (1964), Kirk et al. (1968) and Wälchli (1969) found a reduction of static or impact bending strength of a similar order of magnitude. Recently, Sorsa (1973) confirmed these findings in a series of tensile tests on Scots pine *(Pinus silvestris)*. Sorsa reports of a 64 % reduction of tensile strength for a 5 % weight reduction.

4. MATERIALS AND METHODS

4.1. Materials

The test material consisted of 0.6-metre long ground level bolts of 17 salt impregnated Scots pine poles. The poles were selected from various locations in Southern Sweden and had been in service for 25 - 30 years. 15 bolts (series A-I, K-P) were prepared for tensile tests, as well as compression tests, whereas the remaining bolts (series R-S) were tested in tension only. Each bolt was split into 10 blocks (Fig. 3). Four blocks (1-4) were used for tensile tests, four blocks (5-8) were used for compression tests and two (9-10) were saved as a reserve. Each block was split and sawn into small test pieces (Fig. 4) leaving one sample for each 10 mm of pole diameter. These small 10 mm steps were chosen in order to ensure a tolerable homogeneity in the degree of soft rot attack within each specimen. This, at the same time, made it impossible to adapt the specimen size and shape to any known standard. Samples from blocks 1, 3, 5, 7 were tested in green condition. Samples from blocks 2, 4, 6, 8 were tested after having been conditioned to approximately 15 % moisture content (20°C, 74 % R.H.). Members of series R-S were tested in green condition only.

The microflora present was the one typical of salt-impregnated poles in situ. A microbiological identification as well as a chemical analysis of typical salt-treated poles is put forward by Henningsson and Nilsson (1976).

4.2. Methods

Compression and tension testing was carried out in a mechanical testing machine using a constant strain rate of approximately 1 ^{0}/00/min corresponding to a test duration of approximately 5 minutes per specimen. Fixed crossheads were used for the compression tests and hinged wedge-grips were used for the tensile tests. The applied load was measured by a strain-gage load cell and the corresponding deformation was measured by two Linear Variable Differential Transformers. The two signals were fed into an X-Y recorder, calibrated and used for a direct plot of stress-strain diagrams (Fig. 5). Tensile deformations were measured on the specimens directly (gauge length: 30 mm) whereas compression deformations were measured primarily by registering the moving of crossheads (gauge length: 35 mm). For a great number of compression specimens, however, measurements on the specimens directly (gauge length: 17 mm) were conducted. No significant difference between the two methods was registered.

Moisture content and annual ring width were determined for all specimens. Ovendry specific gravity was determined for all tension specimens. For this purpose a small piece was cut out near the area of failure. Mercury displacement was used for volume determination. Green specific gravity was determined for all compression specimens. Green volume was determined stereometrically by using a sliding gauge.

Soft rot degree (SRD) in latewood and earlywood was determined for all specimens. An estimate of decay was formed from the light microscopic appearance of thin sections compared with a standard defined in Table 1 and illustrated in Fig. 6.

Table 1. Definition of soft rot degree (SRD)

SRD class	Appearance of Cross Section	Area of Disintegrated Secondary Wall (%)
0	No cavities	0
1	Only few, scattered cavities	1 - 10
2	Numerous cavities in most cells	10 - 40
3	Cavities abound. Often confluent	40 - 90
4	Total or almost total disintegration of secondary wall	90 - 100

When nothing else is stated, *the soft rot degree relates to latewood.*

Scanning electron microscopy was used in trying to reveal the soft rot mechanism of progressive decomposition as well as the failure mechanism of soft rotted wood.

Equilibrium moisture content corresponding to 9 different relative humidities was measured for all decay classes. Very fine chips from *one* block representing each of the decay classes were exposed to relative humidities controlled by saturated salt solutions. Vacuum corresponding to the various vapor pressures was obtained in a desiccator. Moisture content was accepted as being at equilibrium when consecutive readings at 48-hour intervals did not differ more than 0.05 %. One complete adsorption-desorption cycle was carried out during an 8-month period. Ovendry (103°C) condition was used as a basis.

5. RESULTS AND DISCUSSION

5.1 Strength and Elasticity

The sampling method requires a nonrandom selection of specimens from the different soft rot decay classes. The decrease of soft rot decay towards the pith causes specimens from decay class 4 to be selected near the pole surface and specimens from decay class 0 to be selected from some depth below the pole surface. Some consideration should therefore be given to the fact that there is known to be a systematic variation in annual ring width from pith to bark and that at the same time most properties are dependent on annual ring width.

The annual ring width increases from bark side to pith (Table 2), the difference between class 0 and class 4, however, being as small as 0.35 mm.

Table 2 Average annual ring width as a function of soft rot decay.

Soft rot degree	0	1	2	3	4	Total
Mean annual ring width (mm)	1.20	1.31	1.14	1.01	0.85	1.18
Number of specimens	171	175	100	63	43	552

The annual ring width (ARW) of the total number of specimens (552) is distributed very narrowly around the average value 1.18 mm, only 4 specimens exceeding 2.5 mm. Within such a narrow distribution one could hardly expect any significant variation of green specific gravity (G_G). This is confirmed in an analysis of variance of the regression equation:

$$G_G = A + B \cdot ARW + C \cdot ARW^2$$

Nondecayed specimens were used and no significance for B v C $\neq$ 0 was found. It is concluded on this basis that no adjustments of mechanical properties according to ARW are justified.

Regressions of soft rot decay on strength and elastic properties are depicted in Figs. 7-17. All regression equations are significant at the 0.999 level. One advantage of using soft rot degree as a variable instead of weight loss is that soft rot degree is always easily established, whereas measuring weight loss implies a knowledge of the original weight, which is unattainable in any practical pole assessment.

Test results for the nondecayed wood reflect some well-known facts for strength and elastic properties of small, clear specimens. Compression strength is approximately 1/3 of tensile strength, the difference increasing as moisture content increases. Tensile strength decreases 2.2 %, and compression strength 3.5 % for a 1 % increase of moisture content. The strength data are in agreement with those of other workers (Schlyter and Windberg (1929), Ylinen (1942), Foslie (1963)).

Modulus of elasticity (MOE) in tension decreases 2 % and MOE in compression 3 % for a 1 % increase of moisture content. MOE in tension is of an order of magnitude similar to that found by other workers,whereas MOE in compression seems to be rather on the small side. This might be due to the way in which compression deformation was measured (cf. Sect. 4.2) and is now subject to further investigation.

5.2 Strength and Elasticity as Dependent on Soft Rot Degree

Progressive soft rot decaying of wood causes decreasing strength and elastic properties, eventually resulting in a reduction of compression and tensile strength of 70-78 % and 88-92 %, respectively, depending on moisture content. Similarly, the compression and tension moduli of elasticity are subjected to an ultimate reduction of 72-82 % and 66-71 %, respectively (Table 3 and Fig. 17).

Table 3 Strength and elasticity as dependent on soft rot degree. Numbers in brackets are relative values. All data is based on best regression fit.

		Moisture content	SOFT ROT DEGREE				
			0	1	2	3	4
ULTIMATE STRESS N/mm^2	compression	M > 30%	25.0 (100)	22.6 (90)	18.6 (74)	12.9 (52)	5.6 (22)
		M ≈ 16%	43.4 (100)	40.3 (93)	34.2 (79)	25.2 (58)	13.2 (30)
	tension	M > 30%	92.3 (100)	71.5 (77)	51.1 (55)	30.9 (33)	11.1 (12)
		M ≈ 16%	130.3 (100)	92.7 (71)	60.3 (46)	33.0 (25)	11.0 (8)
MODULUS OF ELASTICITY N/mm^2	compression	M > 30%	7300 (100)	7000 (96)	5800 (79)	3900 (53)	1300 (18)
		M ≈ 16%	10400 (100)	10300 (98)	9000 (87)	6500 (63)	2900 (28)
	tension	M > 30%	12300 (100)	11800 (96)	10200 (83)	7500 (61)	3600 (29)
		M ≈ 16%	15500 (100)	14500 (94)	12500 (81)	9400 (61)	5300 (34)

Reduction of moduli of elasticity and compression strength seem to follow identical patterns (Fig. 17), whereas tensile strength is reduced much more severely. This is especially significant at the earlier stages of attack. MOE and compression strength are reduced at a rate more or less proportional to the area of disintegrated secondary wall (Table 1). Tensile strength is reduced much more rapidly than would be expected from the mere reduction of S_2 area. A 25 % reduction of tensile strength corresponds to approximately 5 % disintegrated S_2 area (SRD = 1). This cannot be explained only by the central part of S_2 having a high proportion of cellulose (high tensile strength) compared with the gross content, but may be an indication of certain *soft rot enzymes being able to penetrate into the cell wall substance to greater depth than what has previously been supposed.*

A great proportion of *tensile failure* in wood is thought to be caused by scission of holocellulose chain molecules (cohesive fracture) (R. Mark,1967). As chain length, and thus, overlap of secondary bonds, decreases, slippage of chain molecules in adjacent rows (shear fracture) becomes more predominant. Tensile failure as caused by shear fracture at the molecular level is inversely related to cellulose molecule length (H.F. Mark,1960; Ifju,1964). An enzymatic *depolymerization of holocelluloses thus causes tensile strength to drop.*

Compression failure of wood is governed by a quite different mechanism. Compression failure of the thin walled early wood is a stability problem, and the resultant buckling of the gross cell wall will hardly be noticed at the molecular level. Compression failure of the thick walled late wood cells is caused by formation of slip planes (Dinwoodie 1968, Keith 1970) in which bundles of cellulose molecules (microfibrils) are folded (Hoffmeyer, to be published). It is unlikely that chain length has any significant influence on the ability of the microfibrils to fold. Therefore, a mere depolymerization of holocellulose should not cause compression strength to drop.

5.3 Strength and Elasticity as Dependent on Weight Loss

Regression of soft rot degree (SRD) on specific gravity (G) (figure 18) reveals a marked drop in G as SRD increases, the first phases of SRD, however, resulting in only little change of G. Both regression equations are significant at the 0.999 level The difference in coefficient of correlation and coefficient of variation is ascribed to the difference in method of volume determination. The mercury displacement method used on small, irregular tension specimens is not as accurate as the stereometric volume determination of regular compression prisms. In addition to this, differences in shrinkage behavior of tension specimens within a single soft rot degree will add to the variation.

The ovendry curve suggests the average ovendry-density of nondecayed wood to be 550 kg/m^3. The different position of the two curves is due to the volumetric shrinkage (β_V), which can be calculated from

$$\beta_V = 1 - \frac{G_G}{G_0}$$

Volumetric shrinkage is seen (table 4) to be highly influenced by soft rot decay. Shrinkage more than doubles from 11.3 % for sound wood to 25.2 % for fully decayed wood.

Table 4. Volumetric shrinkage from green - to ovendry condition for various degrees of soft rot decay.

Soft rot degree SRD	0	1	2	3	4
volumetric shrinkage, β_V %	11.3	11.4	12.6	16.0	25.2

The "green" curve from figure 18 is transformed to express weight loss (WL) as a function of soft rot degree (figure 19). This function is used to express mechanical properties as function of weight loss (figure 20). During the first phases of soft rot attack no change of weight is registered. *This should not be misinterpreted as an indication of no decomposition taking place,* but as a result of hyphal metabolism replacing some of the original substance with hyphal growth, waste products, disintegrated nondigestible products etc. A loss of weight is dependent not only on the loss of produced water and CO_2 but dependent also on a gradual dilution and leaching of waste products. A weight loss of 0.6 % and 5.1 % (Fig. 19) corresponds to an actual loss of S_2 wood substance of 5 % and 25 %, respectively (Table 1). Similarly, a disintegration of approx. 95 % of the latewood S_2-layers and of more than half of the earlywood S_2-layers (SRD = 4) corresponds to a weight loss of only 41 % although 60 - 70 % of the total cell wall volume has been disintegrated. In addition some of the remaining 30 - 40 % of cell wall substance may contribute to weight but not to strength and elasticity as is the case of the loosened S3 cylinder (Fig. 24c). This leaves weight loss as a relatively poor parameter for judging degree of decay and alteration of mechanical properties.

A 5 per cent reduction of weight corresponds to approximately 50 % decrease of tensile strength, and 15 - 25 % decrease of both moduli of elasticity and compression strength (Fig. 20).

5.4 Microscopy

Light and electron microscopy confirm the general view on progressive soft rot attack of softwoods. With a few exceptions the sites of initial attack were distributed randomly within the S_2 layers (Fig. 2 and 6). Some soft rotted latewood was observed, however, to present a highly ordered pattern of initial cavities, i.e. each cell having 4 cavities placed in the cell corners.

Cavities are much more conspicuous in latewood than in earlywood (Fig. 2 and 6). This confirms the findings of Savory (1954). No earlywood decay was registered until latewood cells had a soft rot degree (SRD) equal to 1 (Fig. 21) and as latewood approaches SRD = 3, earlywood decay is still only at the SRD = 1 level.

Biodeterioration other than caused by cavity-forming soft rot hyphae was observed in a number of specimens. A typical appearance was a corrosion of the S_3 cell wall. Bacterial attack, especially of the middle lamella, similar to what has been noted by Greaves (1969), was also observed. In the few cases in which these kinds of attack were thought to be severe enough to influence the test results, these results were left out.

The micro failure mechanism of soft rot decayed wood in tension resembles that of nondecayed wood. The micro failure is a compound shear and tension failure. Shear failure takes place in the S_1 region (Figs. 22a - b and 24c), corresponding to observations made on nondecayed wood by R. Mark (1967) and others. The subsequent tensile failure of S_2 differs from nondecayed wood in being more brittle. In a nondecayed wood fiber tensile failure of S_2 shows most frequently as long bundles and sheets of microfibrils having been pulled apart. A soft rot decayed fiber shows a remarkably even surface of fracture. This type of failure is seen much more frequently in decayed wood than in nondecayed wood. The fiber shown (Fig. 22, b), which is from wood of class SRD = 1, has only very few sheets or bundles sticking up, suggesting perhaps a predominant, cohesive like fracture of microfibrils (Fig. 22, c) caused by a long distance enzymatic activity.

5.5 Equlibrium Moisture Content

Sorption isotherms (Fig. 25) for wood of various degrees of soft rot reflect the observation made in practice that soft rot decayed wood tends to hold more water than nondecayed wood under equal climatic conditions. This is not surprising as far as the capillary range goes. Capillary pores are supposedly more numerous in decayed wood than in nondecayed wood. Measurements on micrographs of the diameter of the hyphae-made pores suggest (Kelvin equation) that water starts condensing in the smallest hyphae-made cavities around RH $\approx$ 99 %. Water may even condense below this value in submicroscopic enzyme-produced pores. An increase of relative humidity from RH = 97 % to RH $\approx$ 100 % causes an 8 % and 23 % increase of equilibrium moisture content of nondecayed and heavily decayed wood, respectively.

Water sorption below the capillary range, however, would be expected to be influenced by the very nature of soft rot metabolism, removing hygroscopic substances such as holocelluloses and leaving less hygroscopic material like lignin. This, however, does not seem to be of any significance. Throughout the range of surface sorption, wood of decay class 4 holds 1.2 - 1.4 % more water than nondecayed wood. This may be caused by the enzymes penetrating and opening up regions not previously accessible to water molecules, thus increasing internal surface area. BET analysis of the adsorption isotherms shows an increase of internal BET surface area of 14 %. Another possible factor could be a systematic variation of the concentration of remaining impregnation salt.

The significance of soft rot hyphal "sorption mechanism" on the gross equilibrium moisture content of decaying wood is not very well known. From what is known from *Basidiomycetes* (i.e. Ammer, 1964), respiratory produced water of live hyphae alters sorption isotherms of the gross wood. The present sorption isotherms are based on wood with no live hyphae (cf. Section 4.2). "Equilibrium" moisture content of soft rot decayed wood in situ may, therefore, be considerably higher.

The average equilibrium moisture content (Table 5) of the 264 samples conditioned at 20°C, 74 % R.H. and grouped according to their decay class is plotted in Fig. 25. This data confirms the general trend of the sorption test, and the position of the data between adsorption isotherms and desorption isotherms is interpreted as a result of the relative humidity *cycling* around R.H. = 74 %.

Table 5. Equilibrium moisture content of conditioned specimens (blocks Nos. 2, 4, 6 and 8).

SRD	Eq. Moisture Content	Standard Deviation	Number of Specimens
0	16.31	0.635	97
1	16.67	0.493	75
2	16.82	0.592	40
3	17.05	0.837	26
4	17.49	0.898	26

6. STRENGTH OF A SOFT ROT DECAYED POLE

6.1 General

The permissible bending stress is an important strength factor in wood pole design. In trying to evaluate the influence of soft rot attack on the strength properties of a pole, static bending strength is by far the most important property to consider. This is due to the fact that soft rot attack is located in the moist region around ground level. Soft rot attack has a maximum around 50 - 150 mm below ground level (Liese (1963), Friis-Hansen (1976)) depending on the kind of surrounding soil. This region coincides with that of maximum bending moment. Furthermore, Liese (1963), Gersonde and Meyer (1964), Sorsa (1973), and Friis-Hansen (1976) have shown that soft rot attack of salt-impregnated poles is stronger in the outer fibres of a pole gradually decreasing to little or no attack in the heartwood. This means that fibres most heavily strained in bending are at the same time most severely weakened by soft rot attack. Bending strength is proportional to the cube of the pole diameter.

Holmgren (1958) and Bohannan et al. (1974) pointed out the fact that maximum strain is not necessarily to be found in ground level cross sections. The calculations made by Holmgren suggest that the cross section most likely to fail is the one having a diameter 1.5 times the pole top diameter. In practice this cross section is located approximately 2 metres above ground level. The strain difference between the two cross sections, however, is insignificant (order of magnitude ≈ 2 %) in this connection as $^{1)}$ ground level cross sections hold most water (lowering of strength) and $^{2)}$ even the very mildest soft rot attack (SRD = 1 in outermost ring only) results in more than a 2 % weakening of ground level cross sections.

Other design stresses are less affected: shear strength is proportional to the square of the pole diameter, and stability is influenced only by the gradual reduction of pole fixity at ground level.

Bending strength of a material is not a basic strength property but a compound strength made up of compression, tensile, and shear strength. Bending strength of a pole is determined by the compression strength, tensile strength and elasticity of each individual wood element of a cross section. Shear strength will be decisive under very special circumstances only.

For wood of high quality, tensile strength is superior to compression strength, whereas for low quality wood, tensile strength is inferior to compression strength. As a result, bending failure of a high quality pole (slow-grown,knot free) will show first as a compression failure (fiber buckling), eventually followed by a tensile failure. A low quality pole (fast-grown, knots) will show no compression failure prior to tensile failure. As soft rot reduces tensile strength more than compression strength (cf. section 5.2), most soft rot infected poles will show a failure mechanism similar to that of a sound,low quality pole. In addition, the failure is brittle, with the surface of fracture being very typically shortfibered (Fig. 26).

6.2. Method of calculation

Design of poles is based on an assumption of a homogeneous cross section. Although density - and thus strength and elasticity - varies systematically over a cross section (cf. section 5.1) this assumption is in general permissible. When dealing with calculation of the strength of a soft rot infected pole, the assumption of homogeneity is no longer valid.

One way of dealing with this problem is by visualizing a cross section as made up of a large number of elements, each having individual homogeneous mechanical properties. In this way specific criteria of stress strain, and failure can be appointed to each element according to varying soft rot degree. This use of the "finite element method" will be the subject of a later publication.

For most practical purposes such sophisticated methods are superfluous. In practical pole assessments no more than 1 - 2 increment cores are taken from each pole. These increment cores may not always be taken from the weakest cross section, and even so, one or two increment cores may not be representative of the true decay situation of the whole cross section.

A simplified method of calculating the static bending moment (modulus of rupture) of a soft rot decayed pole is presented below. A cross section is visualized as made up of a number of *concentric rings* each having individual, homogeneous strength properties and elastic properties. The number of rings is limited to 1 ring per 2 cm diameter. 5 grades (0 - 4, cf. table 1) of strength properties and elastic properties are used. A plane strain distribution (Navier) is assumed, and normal stresses are omitted. Modulus of elasticity in tension is assumed to be equal to modulus of elasticity in compression.

Modulus of rupture, MOR',of a nonhomogeneous cross section as shown in figure 27 is calculated by means of the concept of "transformed cross section" by:

$$MOR' = (MOR_i)_{max} = \left[\frac{E}{E_i} \cdot \frac{2 \cdot I_{t,i} \cdot s_i}{D_i}\right]_{max} \qquad (I)$$

The modulus of rupture, MOR, of a nondecayed cross section is expressed

$$MOR = \frac{2Is}{D} \qquad (II)$$

and the residual bending moment of a soft rot decayed pole is expressed

$$REDUC = \frac{MOR'}{MOR} = \left[\frac{E}{E_i} \cdot \frac{I_{t,i}}{I} \cdot \frac{s_i}{s} \cdot \frac{D}{D_i}\right]_{max} \qquad (III)$$

where:

$$I_{t,i} = \sum_i^n \frac{E_i}{E} \cdot \frac{\pi}{64}\left[D_i^4 - D_i'^4\right] \qquad (IV)$$

and:

MOR_i = modulus of rupture of entire cross section delimited by D_i

E = modulus of elasticity of nondecayed wood

E_i = modulus of elasticity of ring no. i

I = moment of inertia of entire pole cross section

$I_{t,i}$ = transformed moment of inertia of entire cross section delimited by D_i.

D = diameter of pole

D_i = outer diameter of ring no. i

D_i' = inner diameter of ring no. i

s = ultimate stress of nondecayed wood

s_i = ultimate stress of ring no. i

6.3 Modulus of rupture of a soft rot decayed, salt-impregnated pole

Equations (I) or (II) can be used to calculate the failure load of a decayed pole. If equation (I) is used, a size factor is most likely required to account for the difference between the ultimate stress of small, clear specimens and structural size poles. When using equation (III), modulus of rupture of a decayed pole is calculated directly by multiplying REDUC by the modulus of rupture (MOR) of a nondecayed pole. This method is used in the following.

The only additional assumption necessary to imply is the *relative* ultimate stresses and moduli of elasticity being equal for small, clear specimens and individual "rings" of the pole.

Relative ultimate stresses $(\frac{s_i}{s})$ and relative moduli of elasticity $(\frac{E_i}{E})$ are appointed in accordance with test results (cf. table 3 and figure 17) as follows:

Soft rot degree	0	1	2	3	4
$\frac{s_i}{s}$	1.00	0.77	0.55	0.33	0.12
$\frac{E_i}{E}$	1.00	0.96	0.81	0.57	0.23

Relative moduli of elasticity are calculated as *average* values of compression and tension data.

Relative ultimate stresses are appointed equal to tension values, as bending failure of a soft rot decayed pole is known to be *initiated* always by tensile failure.

It should be noted that the simplified method implies that when ultimate stress of ring no. i results in maximum bending moment, all elements of ring no!s 1, 2.....(i-1) are supposed to have failed and to lack further bearing capacity. This assumption is valid for those elements of the outer rings being farthest off the neutral axis but is not valid either for tension elements of the outer rings being closer to the neutral axis or for compression elements. The remaining strength and elasticity of these elements cause the reduction of bending moment to be less than calculated. Note that in the example (figure 27), ring no!s 1 and 2 have been fractured before maximum bending moment is obtained for ring no. 3 reaching the ultimate stress, s_3.

Ground level cross sections of soft rot attacked poles generally have a water content well over the fiber saturation point, for which reason only data corresponding to M >30 % is used.

Very few tests have been conducted in order to establish MOR of nondecayed Scots pine poles. When analysing the few test series conducted, it must be considered that the MOR in question is the one at a specific cross section (i.e. "ground level") of a pole. Most failures take place at various distances from this cross section and so the only conclusion to be reached is that MOR at "ground level" is <u>greater than</u> the MOR calculated from test results.

Holmgren (1958), using 16 full size salt-impregnated Scots pine poles, showed that salt poles had an average MOR at ground level greater than 52.4 N/mm^2. He also showed that salt-impregnated poles were significantly weaker (app. 20 %) than unimpregnated poles. All salt poles were tested at a moisture content above fiber saturation point. Water content of unimpregnated poles is not stated and may have been below the fiber saturation point, thus accounting for some of the difference in MOR. The poles were not always failing at ground level, and the average MOR of the failing cross sections was as low as 45.8 N/mm^2.

Dunleavy at el. (1973) tested 30 creosoted Scots pine poles and found an average MOR at ground level greater than 46.4 N/mm^2. This result differs very much from the results of Holmgren, the more so, as creosoting is not assumed to affect strength (Wood at el. 1960).

The Swedish Standard (SEN 360104): "Design of overhead power lines. Supports", using a saftey factor of 2.4, assigns 21.0 N/mm^2 as the permissible bending strength. This presupposes 50.0 N/mm^2 to be approximately the actual MOR. This standard value, being intermediate in relation to the test results mentioned above, is used in the following.

Among the large number of decayed poles tested in situ by Sydkraft (Schmidt and Jacobsson, 1976) 4 series include microscopic examination of increment cores (Friis-Hansen, 1976). These four series, consisting of a total of 36 salt-impregnated poles, offer a unique opportunity of verifying equation III, including data on relative ultimate stresses and relative moduli of elasticity (page 2.9).

Data on horizontal failure load (PFOR) from tests, pole height, pole diameter and soft rot degree is fed into a computer. Original failure load (POPR) is calculated using equation II (s=50 N/mm^2) and data on pole height. REDUC is calculated from equation III. An estimated failure load (PRED) of the decayed pole is calculated by multiplying POPR by REDUC and the error of estimate is expressed by PFOR-PRED.

From the results (figure 28) it is evident that equation III is a powerful tool for predicting modulus of rupture of a soft rot decayed pole. Regression of calculated reduced failure load on failure load from tests show a satisfactory degree of correlation (0.84) and a standard error of estimate (1.06 kN) amounting to 27 % of the mean value of test results.

For practical purposes the use of a regression equation to calculate pole strength is less convenient than using the equation X=Y directly. Using this simple equation causes only little increase of the standard error of estimate (1.07 kN). Results based on X=Y are presented in table 6. The standard error of estimate is reduced from 5.37 kN when neglecting decay to 1.07 kN when considering decay. The very small difference between the average values of calculated failure loads (3.85 kN) and failure loads from tests (3.91 kN) indicates the choice of ultimate stress (50 N/mm^2) being correct.

When judging the accuracy of the method on the basis of standard error of estimate, the *natural* variability of wood must be considered. The coefficient of variation of MOR of sound wood ranges from below 15 %

TABLE 6

Prediction of pole strength from equation (III) using results from 36 pole tests.

```
**********************************************************************
**********************************************************************
**            I           I                          I          I            **
**            I           I                          I          I            **
**    POLE    I ORIGINAL  I      CALCULATED,         I FAILURE  I   ERROR    **
**    NR.     I FAILURE   I  REDUCED FAILURE         ILOAD FROMI    OF       **
**            I   LOAD    I        LOAD              I  TESTS   I ESTIMATE   **
**            I  (POPR)   I       (PRED)             I  (PFOR)  I            **
**            I   (KN)    I   (KN)    I     (%)      I   (KN)   I   (KN)     **
**            I           I           I              I          I            **
**            I           I           I    REDUC     I          I            **
**********************************************************************
**            I           I           I              I          I            **
**     1801   I   7.07    I   3.28    I    46.5      I   2.90   I   -0.38    **
**     1802   I  11.84    I   5.82    I    49.2      I   5.10   I   -0.72    **
**     2301   I  11.20    I   3.95    I    35.3      I   4.60   I    0.65    **
**     2501   I   7.24    I   2.55    I    35.3      I   1.70   I   -0.85    **
**     4501   I   7.12    I   2.91    I    40.8      I   1.50   I   -1.41    **
**        1   I   7.96    I   2.52    I    31.6      I   1.75   I   -0.77    **
**        2   I   5.78    I   1.84    I    31.8      I   1.60   I   -0.24    **
**        3   I   9.36    I   3.29    I    35.1      I   3.75   I    0.46    **
**        4   I   7.26    I   2.35    I    32.3      I   1.80   I   -0.55    **
**     6802   I   9.96    I   3.47    I    34.8      I   3.90   I    0.43    **
**     8102   I   7.47    I   4.52    I    60.6      I   3.40   I   -1.12    **
**     8302   I   6.42    I   1.80    I    28.0      I   1.00   I   -0.80    **
**     5701   I   6.16    I   2.74    I    44.5      I   2.00   I   -0.74    **
**     5702   I   5.39    I   1.80    I    33.4      I   1.50   I   -0.30    **
**     5761   I   8.01    I   3.71    I    46.3      I   4.50   I    0.79    **
**     5762   I   8.48    I   3.29    I    38.9      I   4.40   I    1.11    **
**     6181   I   8.20    I   5.18    I    63.1      I   5.40   I    0.22    **
**     6182   I   4.14    I   1.85    I    44.6      I   2.75   I    0.90    **
**     6231   I   4.86    I   2.79    I    57.5      I   3.70   I    0.91    **
**     6232   I   6.01    I   3.62    I    60.3      I   4.70   I    1.08    **
**     6251   I   6.79    I   3.25    I    47.9      I   4.20   I    0.95    **
**     6252   I   6.35    I   3.62    I    57.0      I   2.40   I   -1.22    **
**     6561   I   8.30    I   3.75    I    45.2      I   5.00   I    1.25    **
**     6562   I  10.38    I   5.03    I    48.5      I   7.10   I    2.07    **
**     6621   I   7.32    I   2.54    I    34.7      I   4.70   I    2.16    **
**     6622   I   6.50    I   2.03    I    31.3      I   1.70   I   -0.33    **
**     6651   I   7.41    I   2.66    I    35.9      I   3.10   I    0.44    **
**     6652   I   7.80    I   3.01    I    38.5      I   2.70   I   -0.31    **
**     2301   I  13.07    I   5.47    I    41.9      I   6.80   I    1.33    **
**     2302   I  15.48    I  10.13    I    65.4      I   9.00   I   -1.13    **
**     2701   I  11.94    I   6.12    I    51.3      I   5.50   I   -0.62    **
**     2702   I  16.63    I   5.85    I    35.2      I   6.00   I    0.15    **
**     5301   I  15.48    I   5.86    I    37.9      I   8.00   I    2.14    **
**     5302   I  17.22    I   8.10    I    47.1      I   6.00   I   -2.10    **
**     2118   I   7.71    I   2.92    I    37.9      I   3.00   I    0.08    **
**     2120   I   6.31    I   5.00    I    79.1      I   3.50   I   -1.50    **
**            I           I           I              I          I            **
**********************************************************************
**                                                                           **
**                                                                           **
**    CALCULATED FAILURE LOAD , MEAN VALUE             =   3.85 KN          **
**    FAILURE LOAD FROM TESTS , MEAN VALUE             =   3.91 KN          **
**                                                                           **
**    STANDARD ERROR OF ESTIMATE,CALCULATED DATA =   1.07 KN                 **
**    STANDARD ERROR OF ESTIMATE,ORIGINAL DATA   =   5.37 KN                 **
**                                                                           **
**    PRESUPPOSED ULTIMATE STRESS = 50 N/MM**2                               **
**    NUMBER OF DATA =    36                                                 **
**                                                                           **
**                                                                           **
**********************************************************************
**********************************************************************
```

for carefully selected specimens to above 25 % for material selected at random from several different populations each having a broad distribution of MOR. As the tested poles (Skåne, Öland, Småland) have hardly been grown in the same forest district and as some of the poles were found to be unusually quick-grown, a high *natural* standard error of estimate would be anticipated. This leaves only very limited inaccuracies to be explained by the prediction method used.

7. SUMMARY

Small clear specimens from 0.6-metre long ground level bolts of 17 soft rot attacked Scots pine poles were tested in compression and tension. All poles were originally salt impregnated and had been in service for 25 - 30 years. The poles were sampled on different locations in Southern Sweden.

Stress-strain diagrams from a total of app. 550 small, clear specimens were recorded. One half of the specimens was tested in air-dried condition (app. 16 % moisture content); the other half was tested in green condition.

Specific gravity, moisture content, annual ring width and soft rot degree were determined for all specimens, the estimate of decay being formed from the light microscopic appearance of thin sections.

Test results for nondecayed wood showed that compression strength is approximately 1/3 of tensile strength, the difference increasing as moisture content increases. Tensile strength decreases 2.2 %, and compression strength 3.5 % for a 1 % increase of moisture content. Modulus of elasticity in tension decreases 2 %, and modulus of elasticity in compression decreases 3 % for a 1 % increase of moisture content.

Progressive soft rot decaying of wood causes decreasing strength and elasticity properties eventually resulting in a reduction of compression and tensile strength of 70 - 80 % and 88 - 92 %, respectively, depending on the moisture content. Likewise, the compression and tensile moduli of elasticity are subjected to an ultimate reduction of 72 - 82 % and 66 - 71 %, respectively.

Compression strength and moduli of elasticity are reduced at a rate more or less proportional to the reduction of cell wall substance. Tensile strength is reduced much more rapidly. A 5 % reduction of the secondary wall substance - corresponding to a 1 % weight loss - results in a 25 % reduction of tensile strength. This severe reduction, together with scanning micrographic evidence of the tensile failure of soft rotted wood, suggests that certain soft rot enzymes are able to penetrate into the cell wall to greater depths than what has previously been supposed.

Cavities are found to be significantly more conspicuous in latewood than in earlywood.

Sorption isotherms for wood of various degrees of soft rot show that throughout the major range of relative humidities, moisture content of heavily attacked wood is 1.2 - 1.4 % higher than that of nonattacked wood. This difference increases for relative humidities close to the saturation point due to capillary condensation in micropores produced by hyphal activity.

A simplified formula for calculating the modulus of rupture of a soft rot attacked pole is presented. The method is based on a knowledge of 1) the average modulus of rupture of a nondecayed pole and 2) the soft rot situation of the worst cross section. Knowledge of the latter is gained from microscopic analysis of an increment core. The formula is tested against 36 poles from a large scale pole test series (Schmidt and Jacobsson, 1976) and a satisfactory result is demonstrated. The variance of calculated pole strengths compared to actual test results was only slightly higher than the natural variance of the modulus of rupture of wood.

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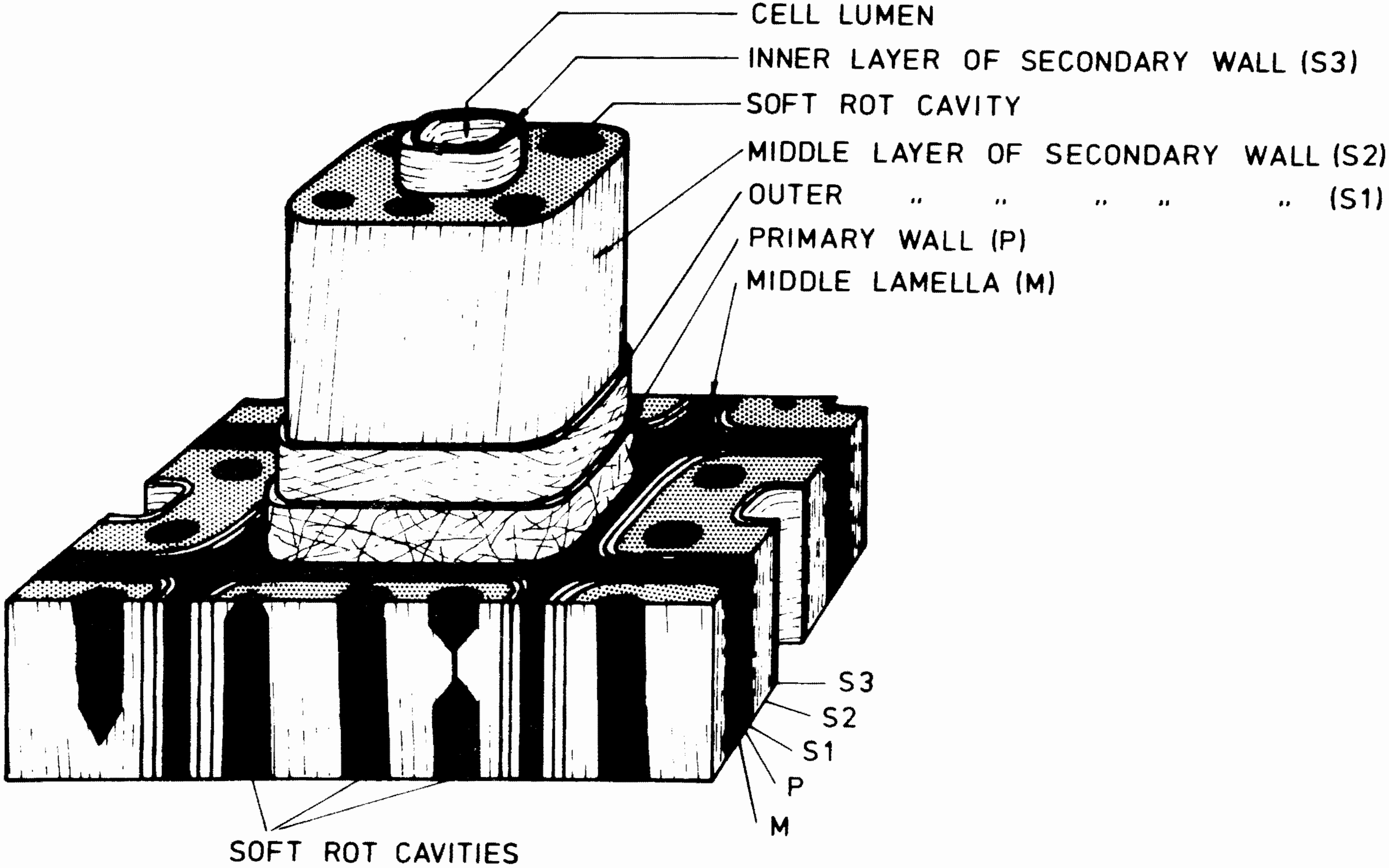
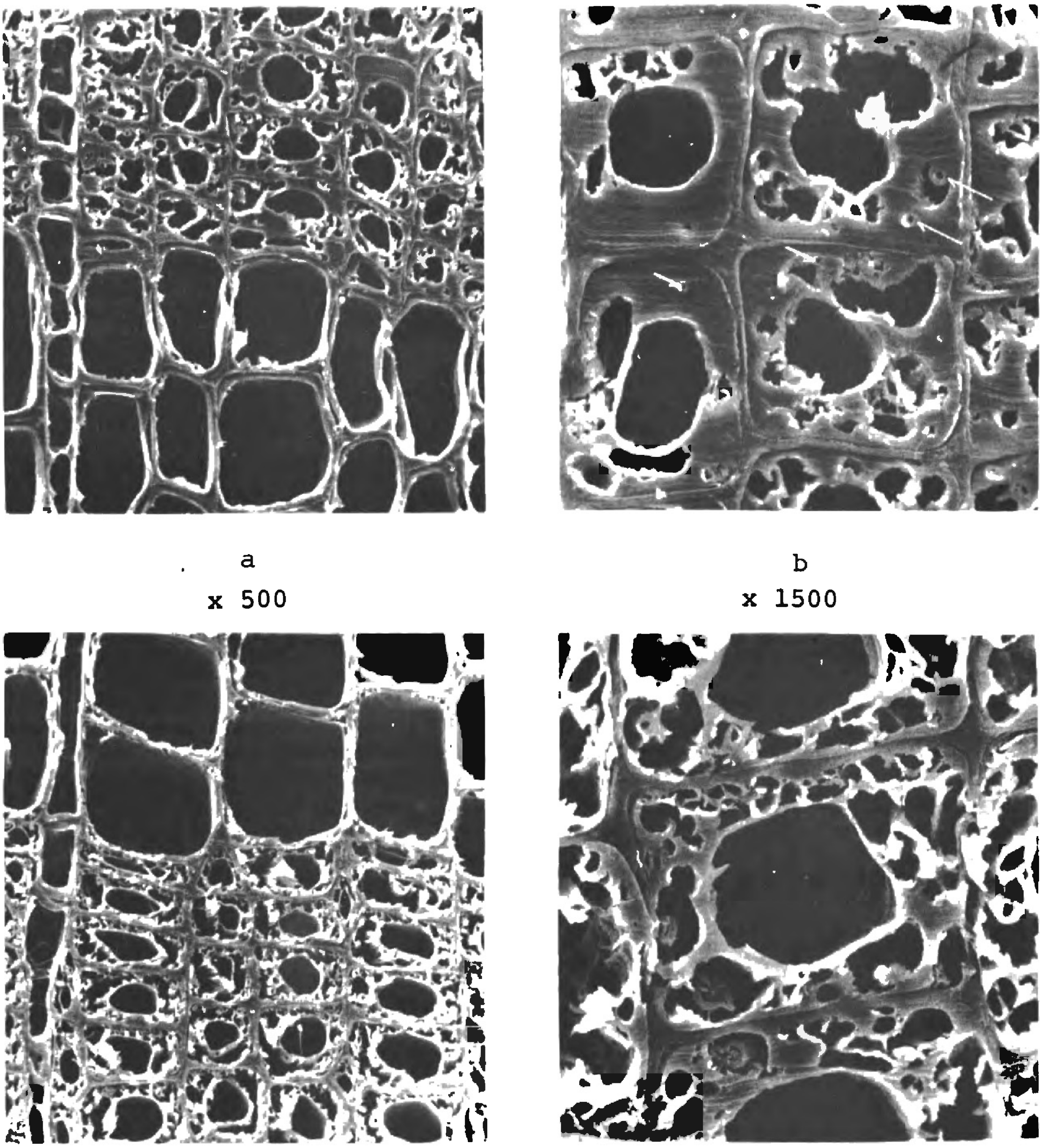


FIG. 1. Diagram of cell wall structure showing microfibrillar orientation and soft rot cavities



a
x 500

b
x 1500

c
x 500

d
x 1500

Figures 2a-2d. Soft rot decayed Scots pine. Scanning micrographs of microtomed cross sections. a-b shows a class 2 decay of latewood cells with no decay of earlywood cells. c-d shows an advanced class 3 decay of latewood cells with some decay of earlywood cells. Note the hollow hyphae in fig.2b.

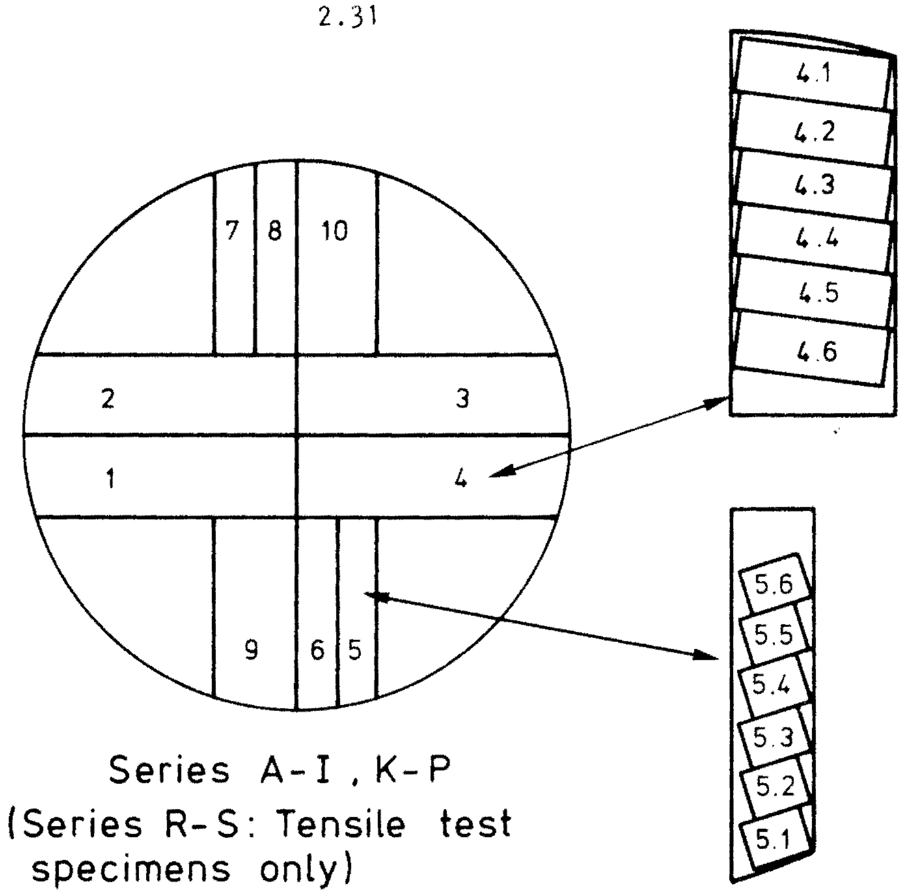


FIG. 3

Diagram of pole cross section. Tensile test specimens are prepared from blocks 1 - 4. Compression test specimens are prepared from blocks 5-8. Blocks 9 - 10 are saved as a reserve

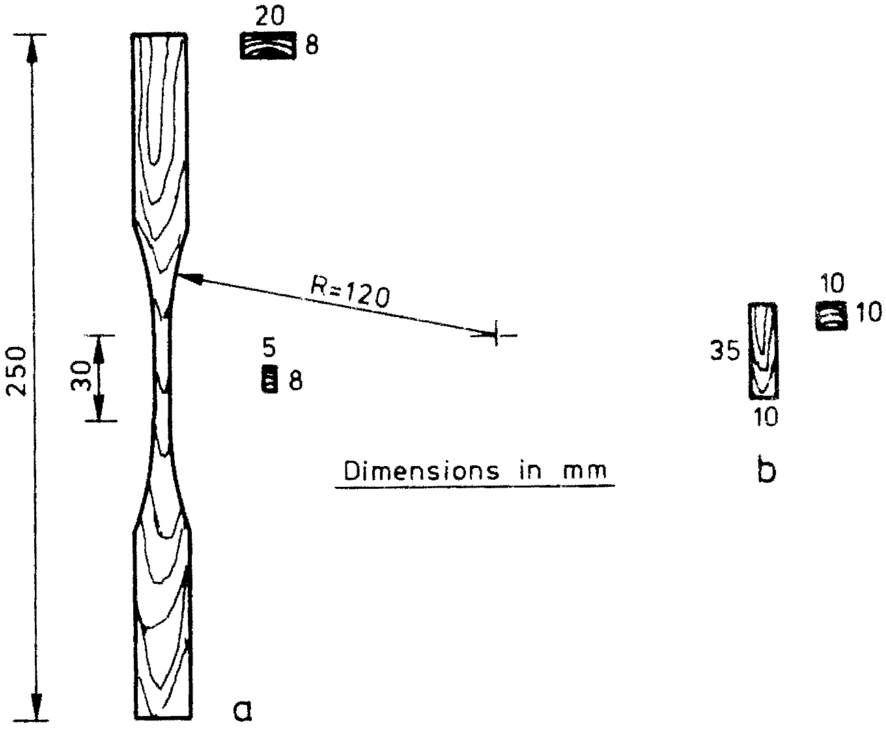
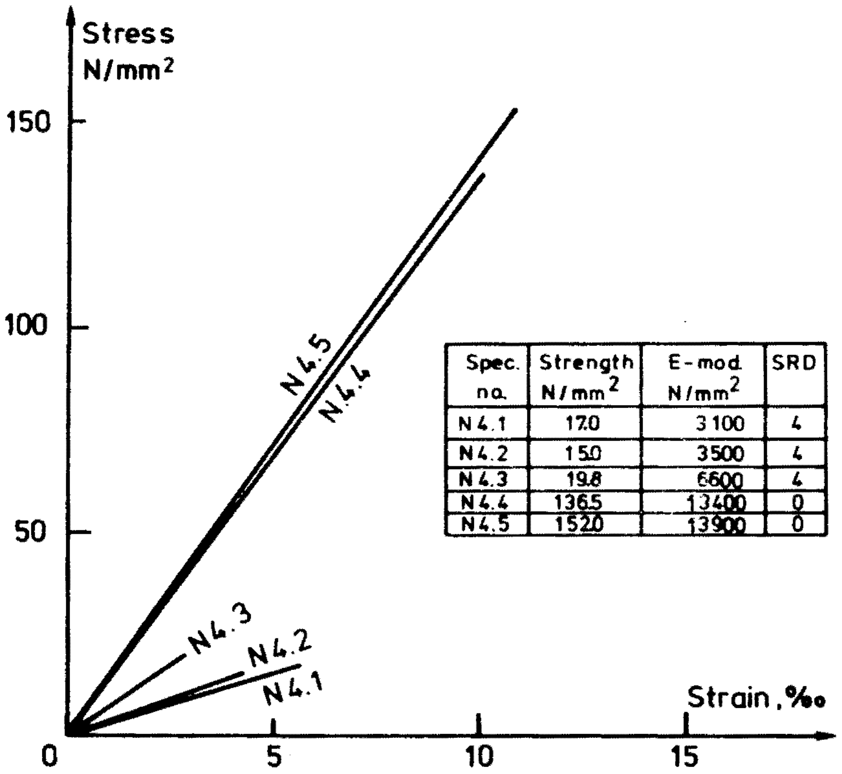


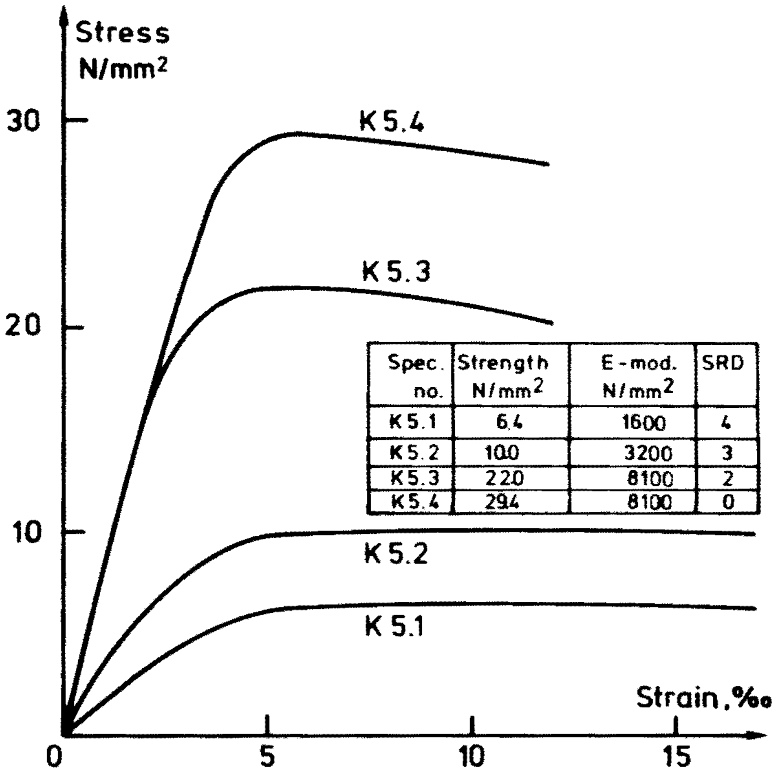
FIG. 4

a. Tensile test specimen. b. Compression test specimen



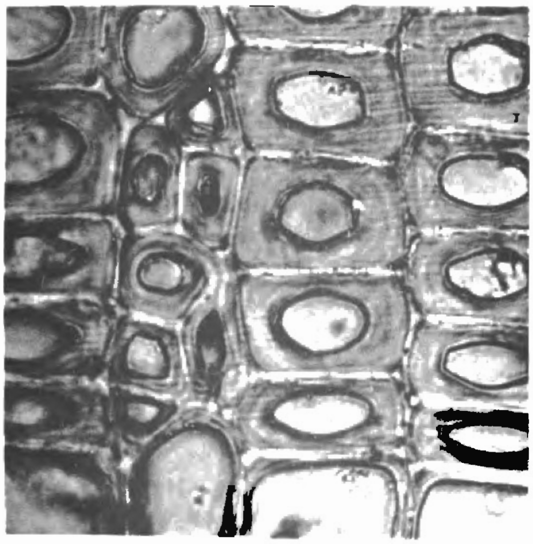
Spec. no.	Strength N/mm²	E-mod N/mm²	SRD
N 4.1	17.0	3 100	4
N 4.2	15.0	3500	4
N 4.3	19.8	6600	4
N 4.4	136.5	13400	0
N 4.5	152.0	13900	0

FIG. 5a
Stress-strain diagrams for tensile specimens from block no. N4.
Moisture content ≈ 16 %

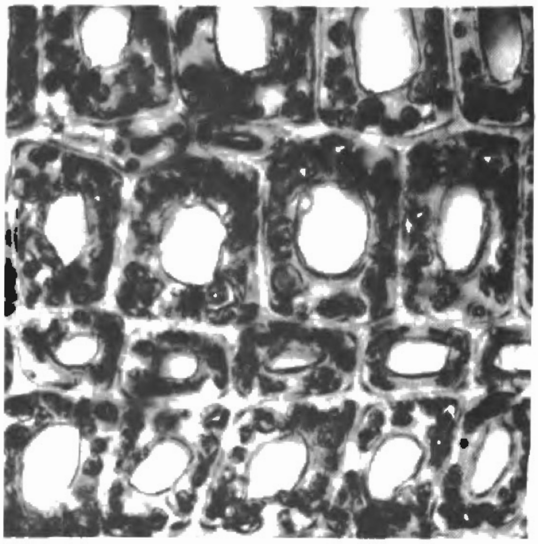


Spec. no.	Strength N/mm²	E-mod. N/mm²	SRD
K 5.1	6.4	1600	4
K 5.2	10.0	3200	3
K 5.3	22.0	8100	2
K 5.4	29.4	8100	0

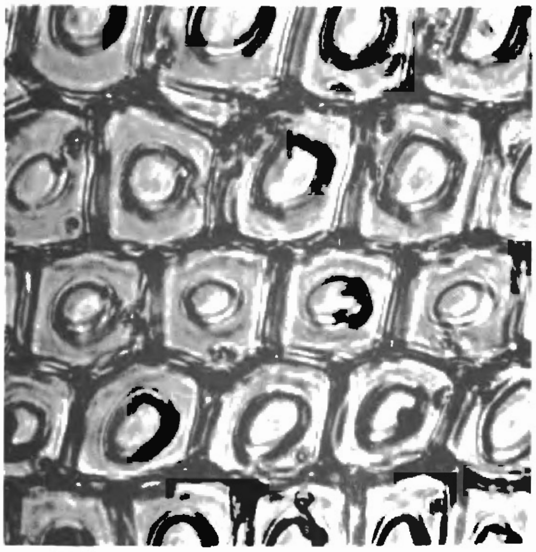
FIG. 5b
Stress-strain diagrams for compression specimens from block no. K5.
Moisture content > 30 %



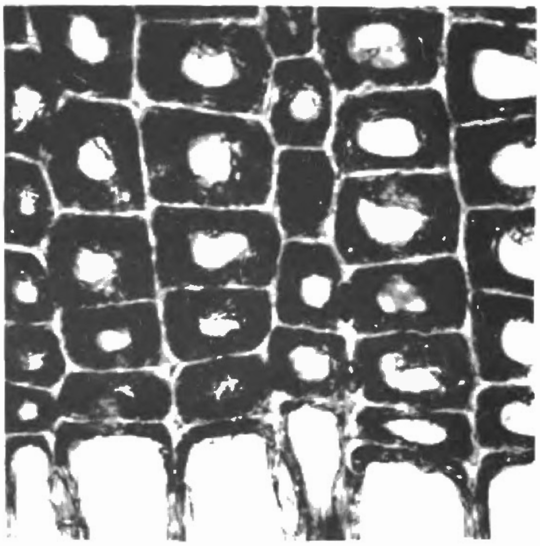
SRD = 0



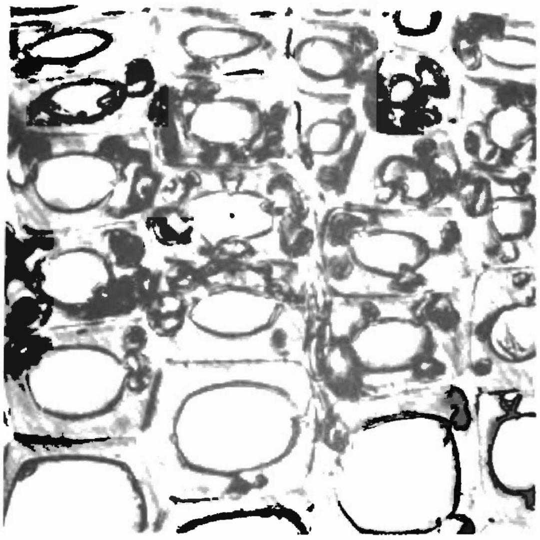
SRD = 3



SRD = 1

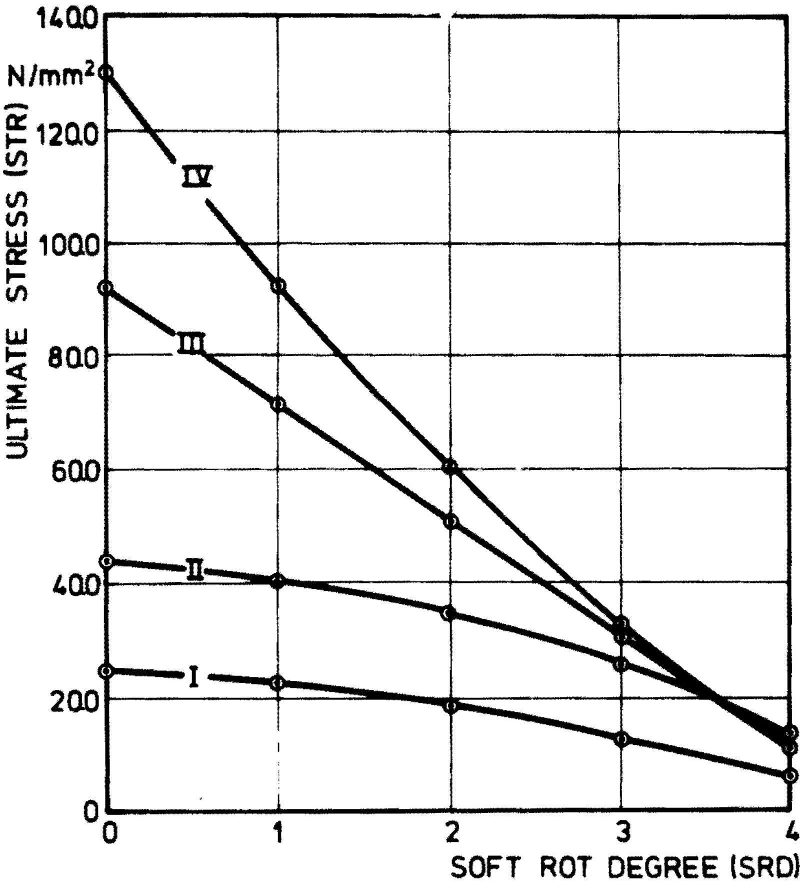


SRD = 4



SRD = 2

FIGURE 6. Light microscopic appearance of thin sections of soft rot decayed Scots pine illustrating the five SRD classes of decay (cf. table 1).
Magnification approx. x 450.



REGRESSION EQUATIONS: SIGNIFICANCE AT THE .999 LEVEL

I. COMPRESSION, $M > 30\%$

II. COMPRESSION, $M \approx 16\%$

III. TENSION , $M > 30\%$

IV. TENSION , $M \approx 16\%$

I. $STR = 25.0 - 1.58\ SRD - .82\ SRD^2$, $r = 0.82$

II. $STR = 43.4 - 1.63\ SRD - 1.48\ SRD^2$, $r = 0.84$

III. $STR = 92.3 - 20.94\ SRD + .16\ SRD^2$, $r = 0.78$

IV. $STR = 130.3 - 40.19\ SRD + 2.59\ SRD^2$, $r = 0.84$

FIGURE 7.

REGRESSION OF SOFT ROT DEGREE (SRD) ON ULTIMATE STRESS (STR).

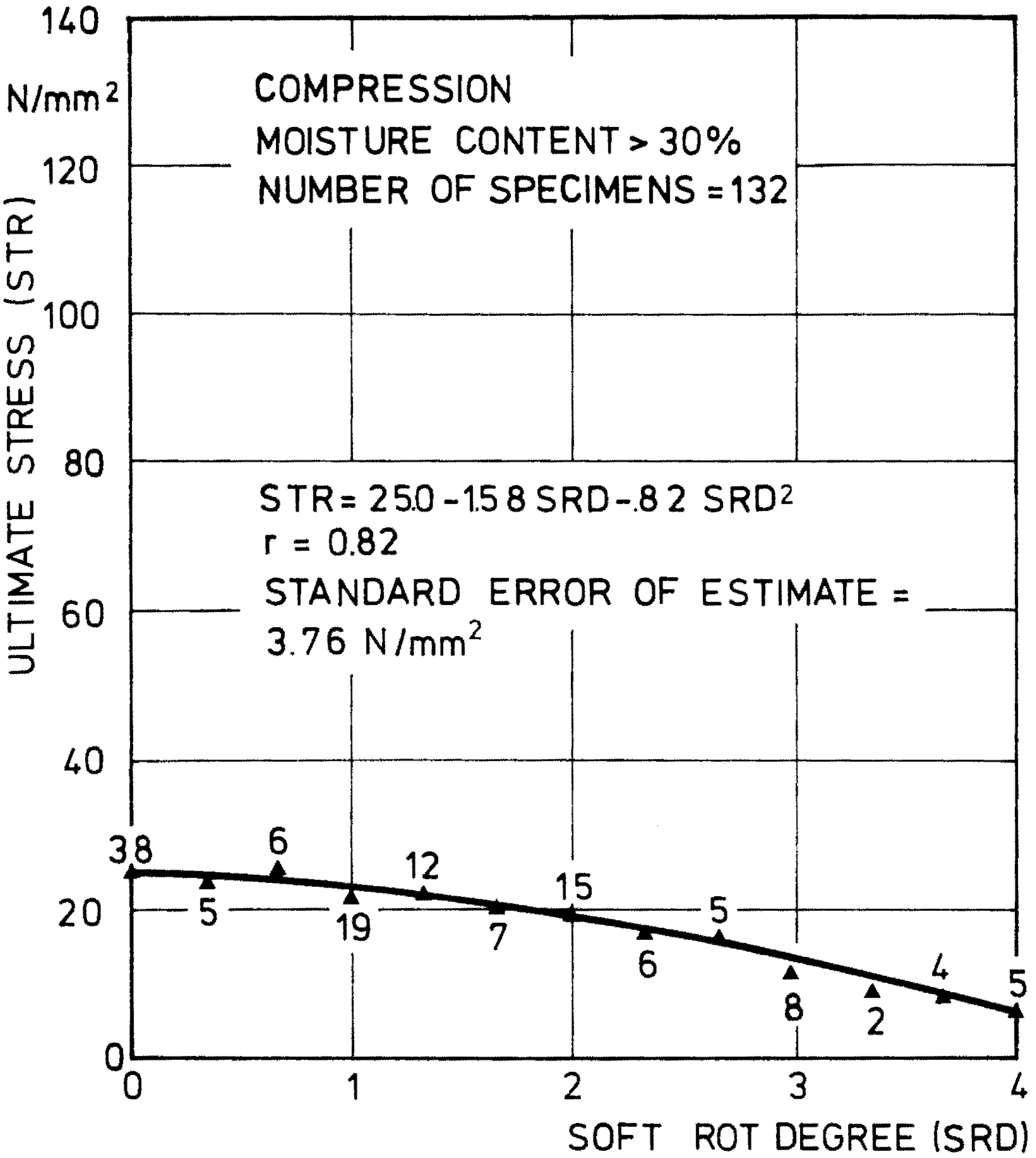


FIGURE 8.
REGRESSION OF SOFT ROT DEGREE ON ULTIMATE COMPRESSION STRESS.

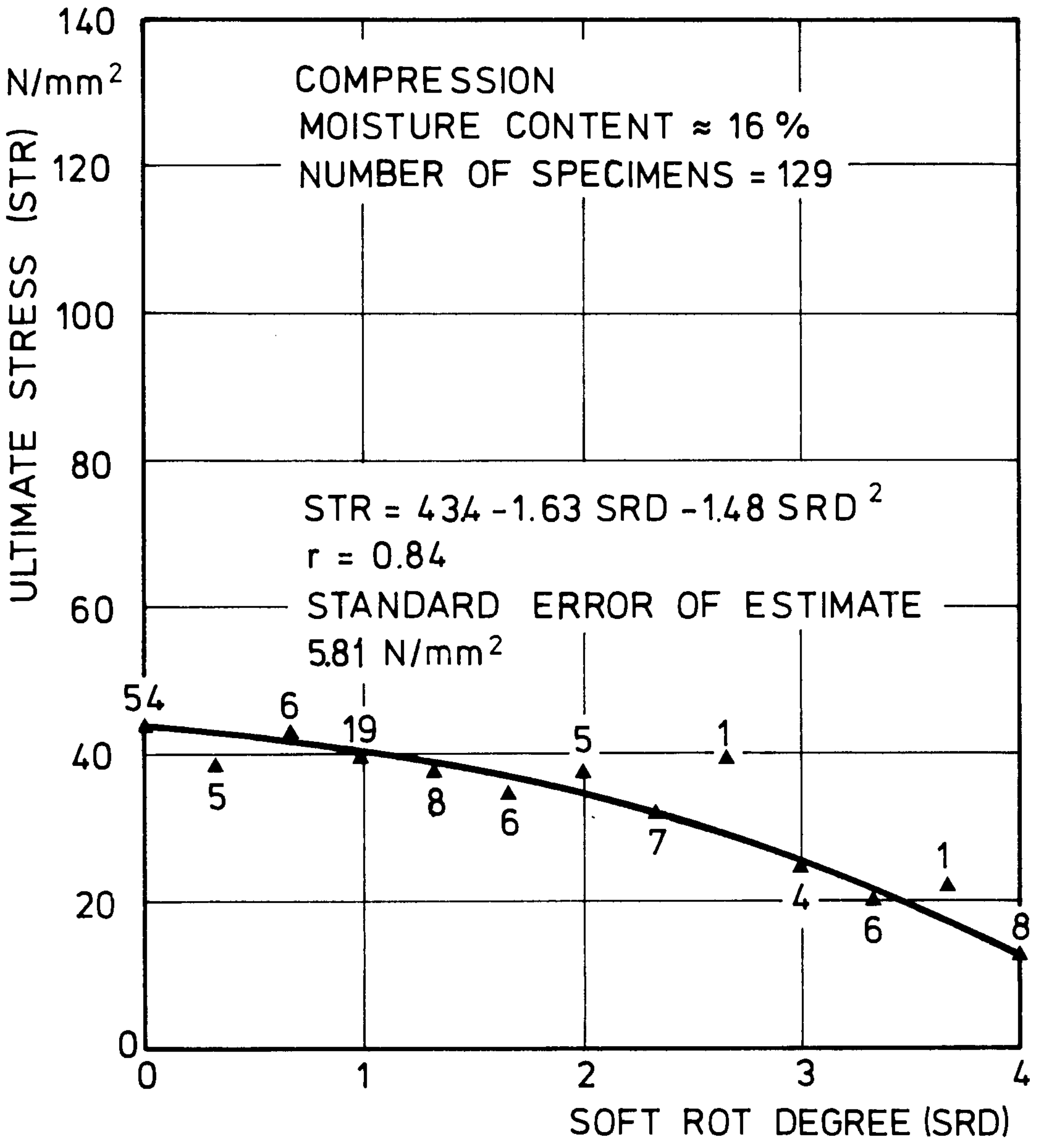


FIGURE 9.
REGRESSION OF SOFT ROT DEGREE ON ULTIMATE COMPRESSION STRESS.

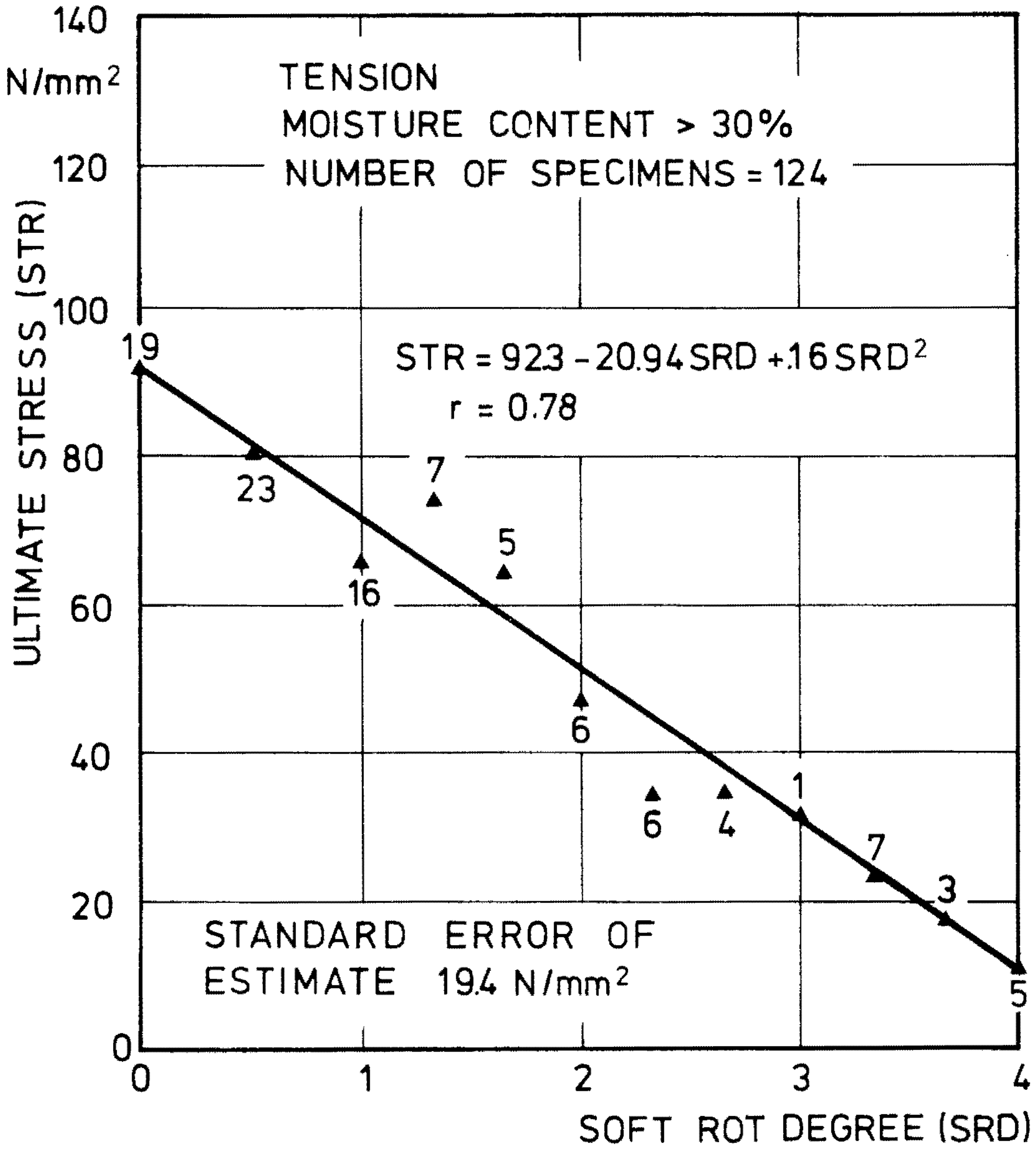


FIGURE 10.
REGRESSION OF SOFT ROT DEGREE ON ULTIMATE TENSILE STRESS.

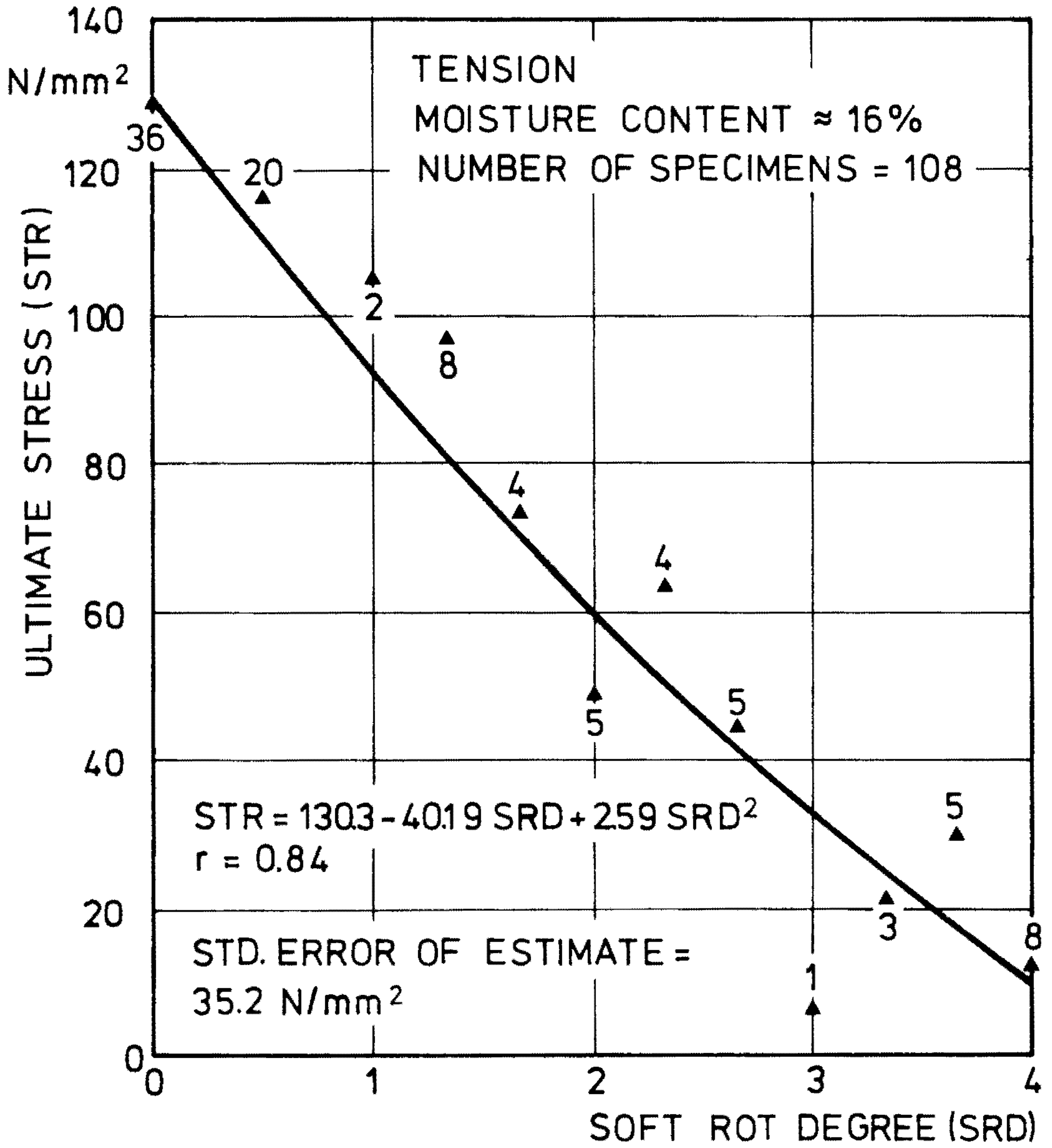
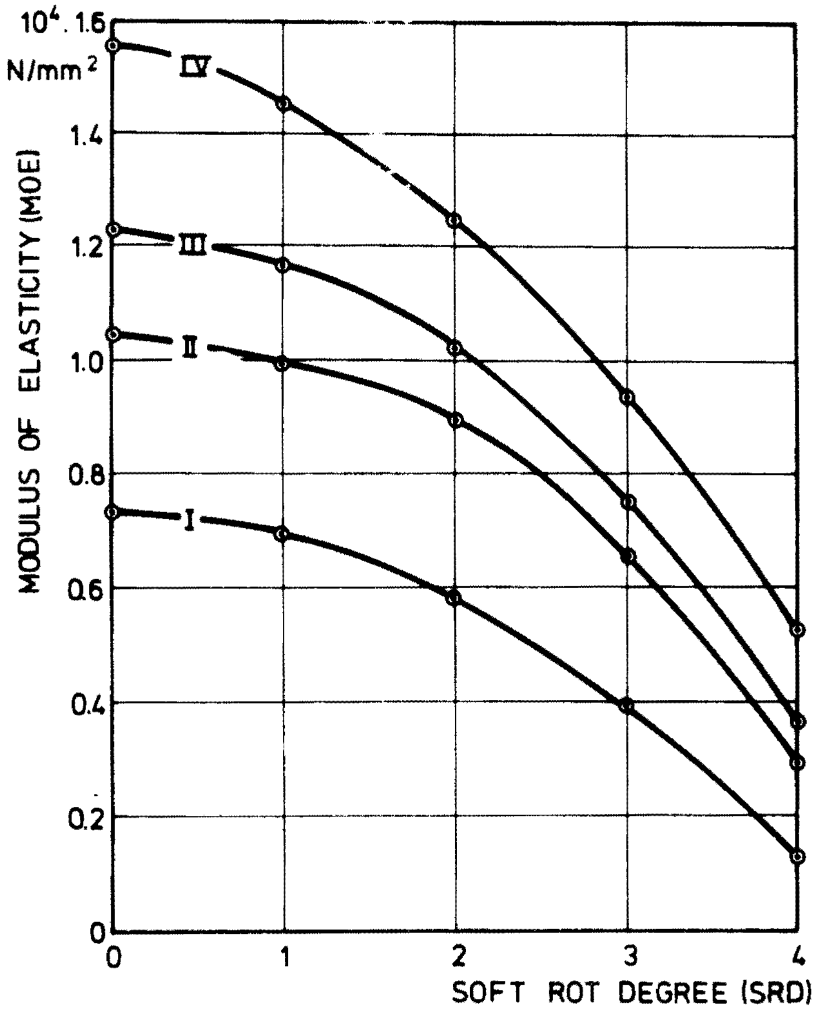


FIGURE 11.
REGRESSION OF SOFT ROT DEGREE ON ULTIMATE TENSILE STRESS.



REGRESSION EQUATIONS:

I. COMPRESSION, $M > 30\%$
II. COMPRESSION, $M \approx 16\%$
III. TENSION, $M > 30\%$
IV TENSION, $M \approx 16\%$

I. $MOE = 7300 - 373.7 SRD^2$, $r = 0.69$
II. $MOE = 10410 + 426 SRD - 574.5 SRD^2$, $r = 0.74$
III $MOE = 12280 + 69 SRD - 556.7 SRD^2$, $r = 0.65$
IV $MOE = 15510 - 461 SRD - 523.9 SRD^2$, $r = 0.74$

FIGURE 12.
REGRESSION OF SOFT ROT DEGREE ON MODULUS OF ELASTICITY

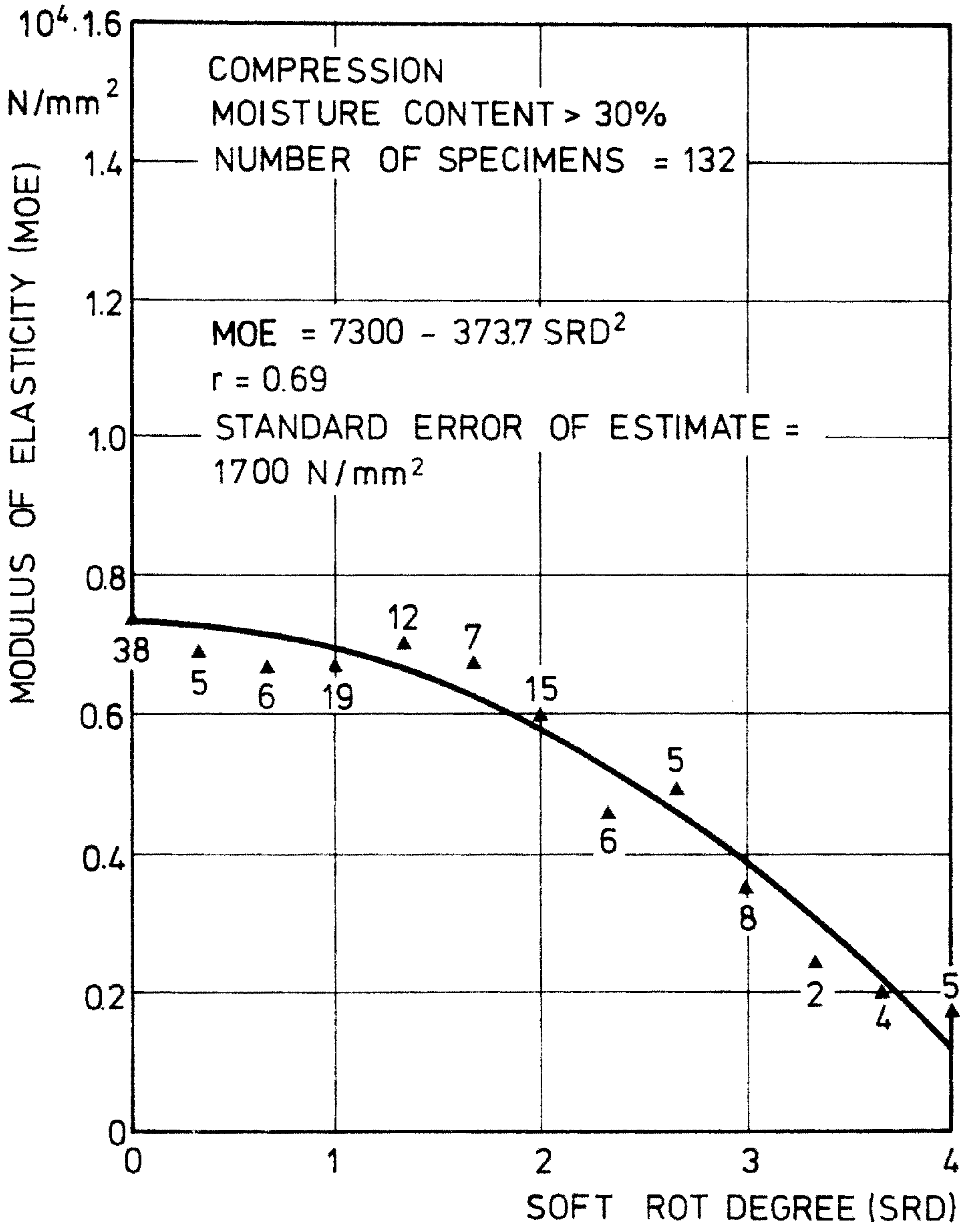


FIGURE 13.
REGRESSION OF SOFT ROT DEGREE ON MODULUS OF ELASTICITY IN COMPRESSION.

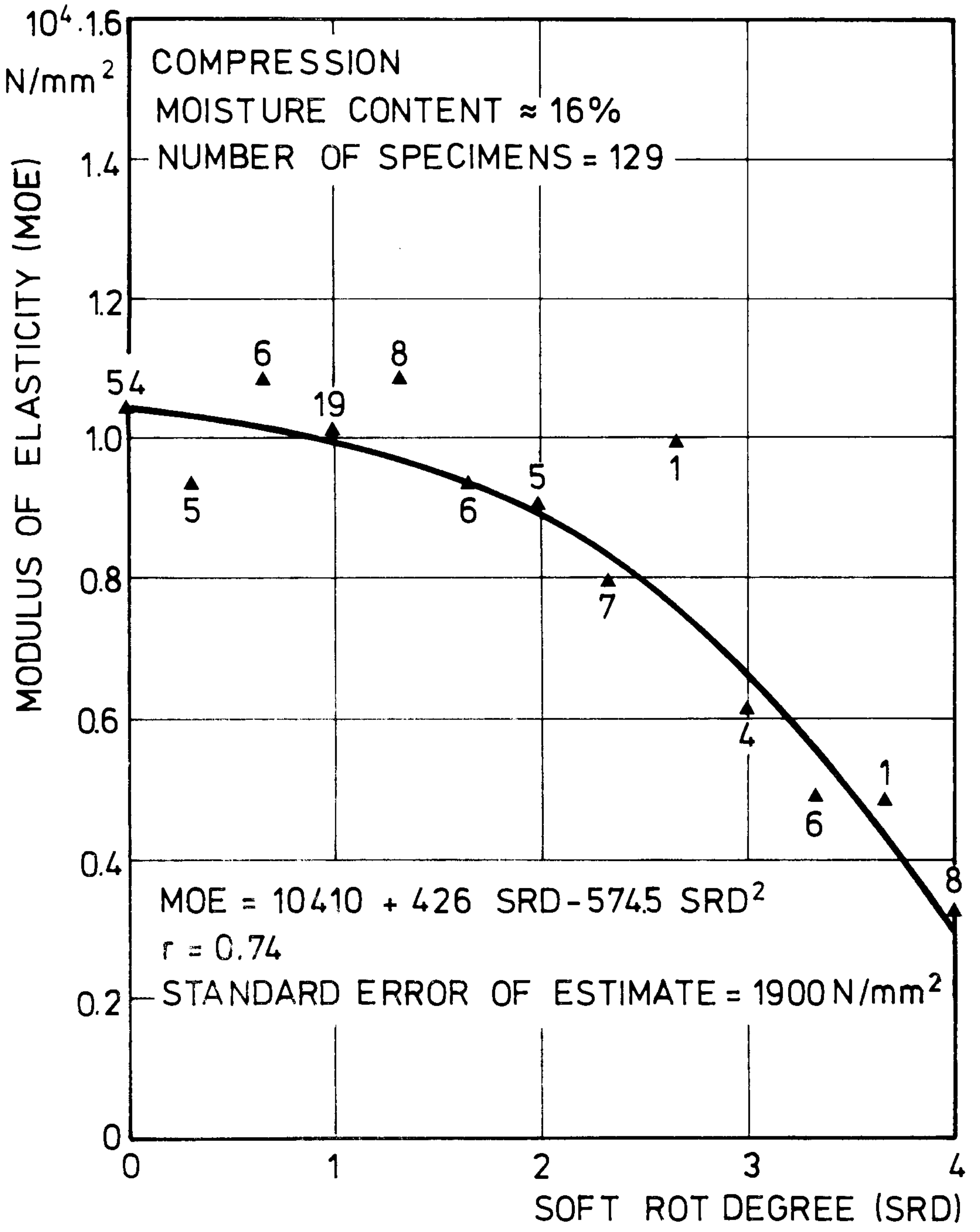


FIGURE 14.
REGRESSION OF SOFT ROT DEGREE ON MODULUS OF ELASTICITY IN COMPRESSION.

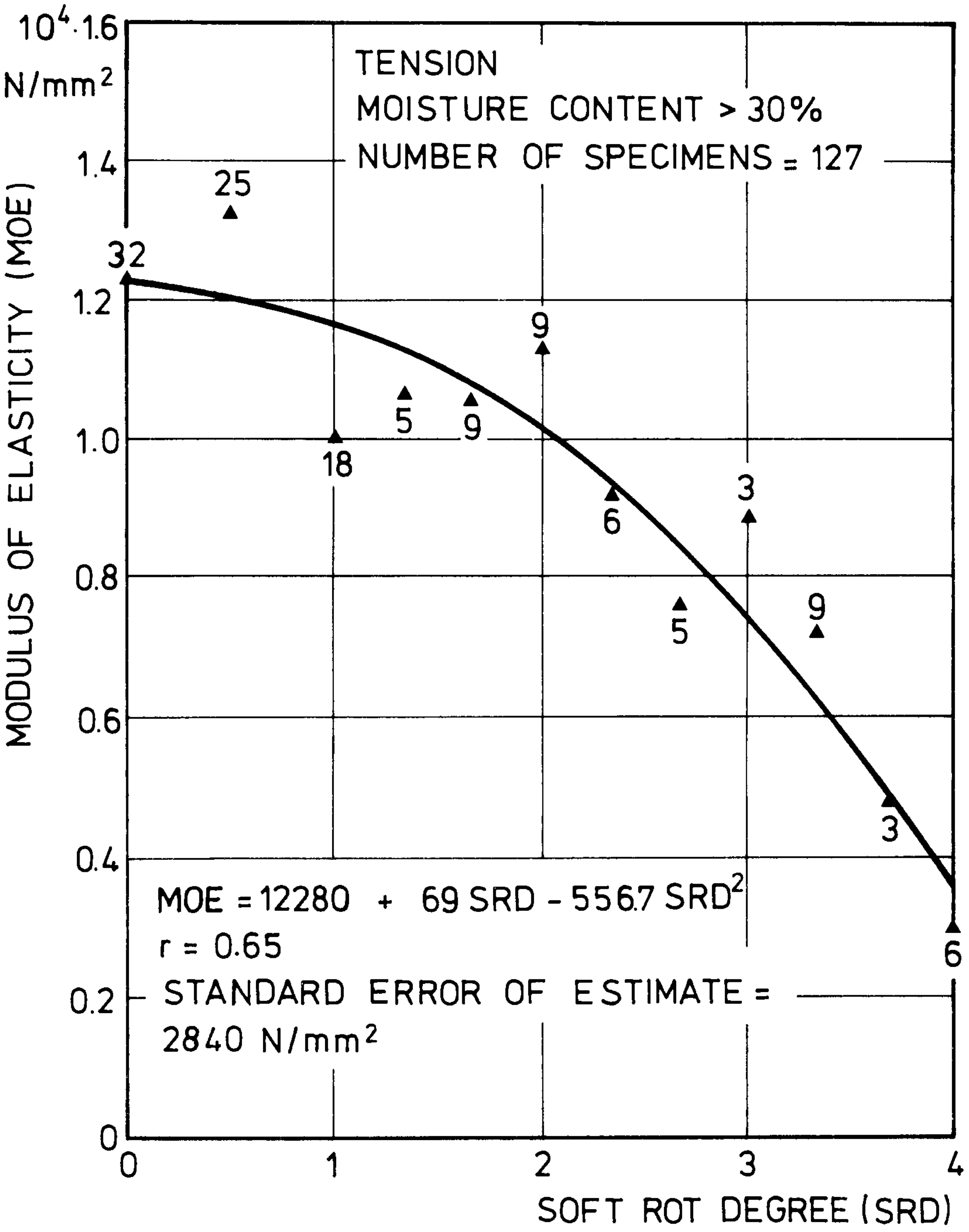


FIGURE 15.
REGRESSION OF SOFT ROT DEGREE ON MODULUS OF ELASTICITY IN TENSION.

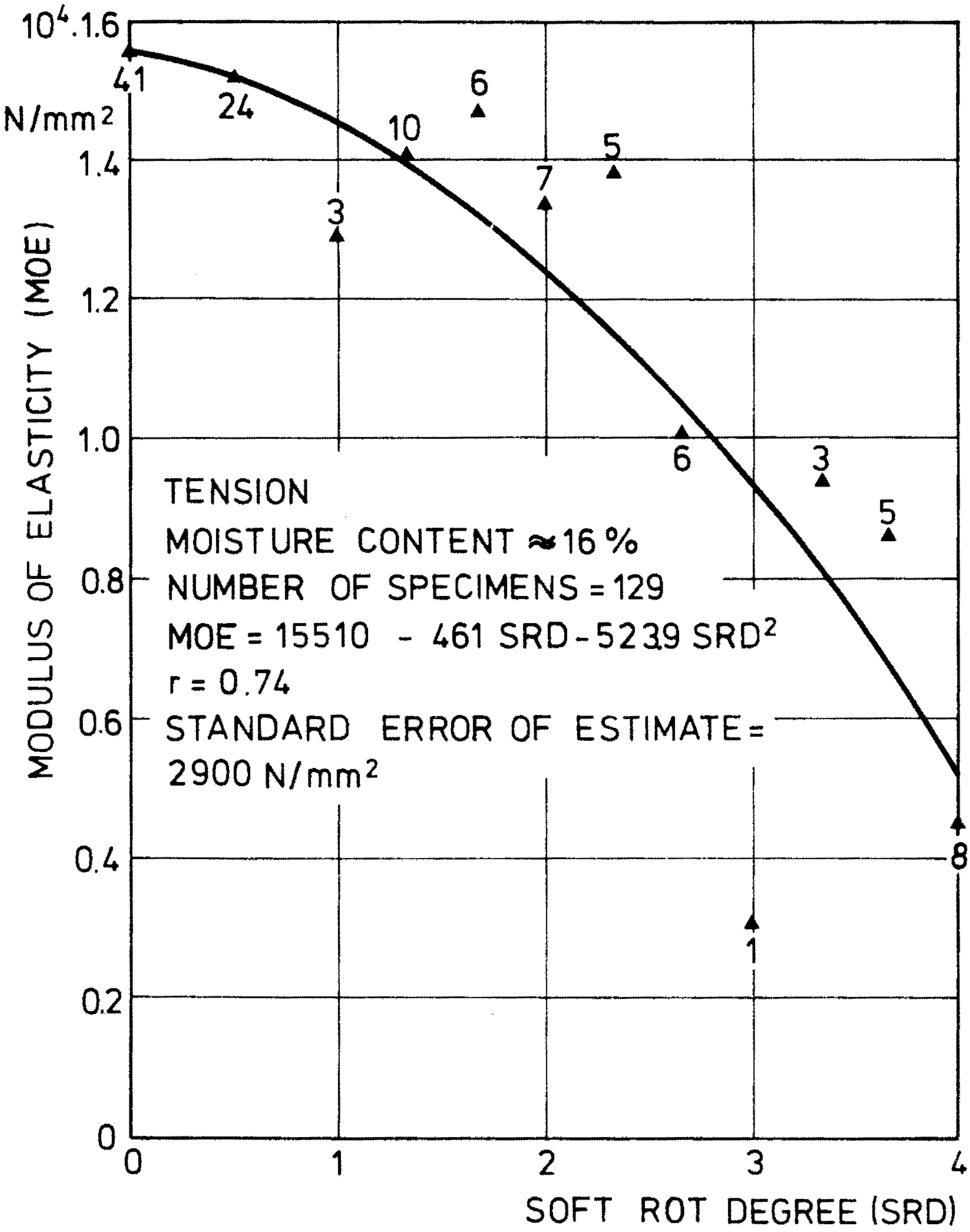


FIGURE 16

REGRESSION OF SOFT ROT DEGREE ON MODULUS OF ELASTICITY IN TENSION.

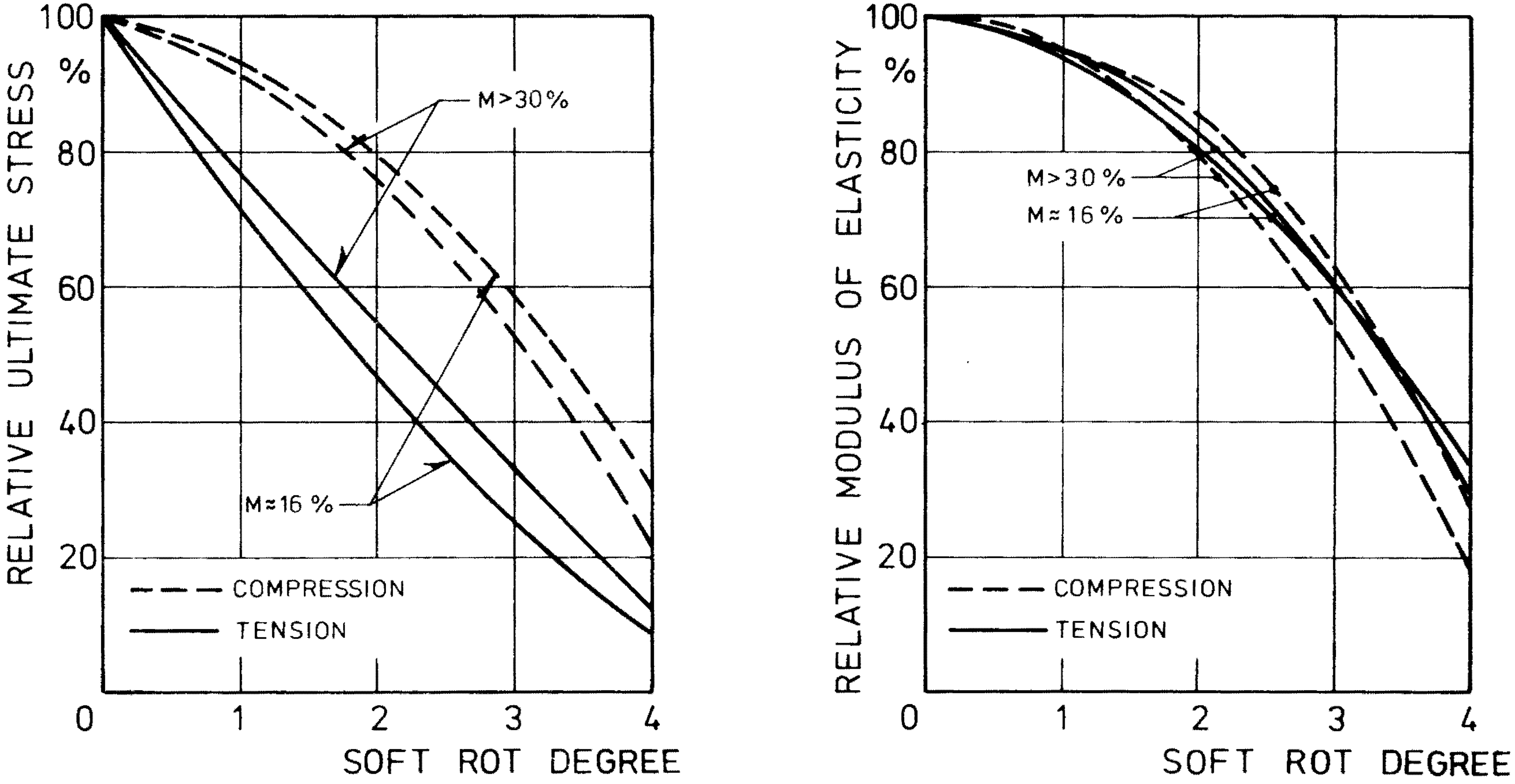
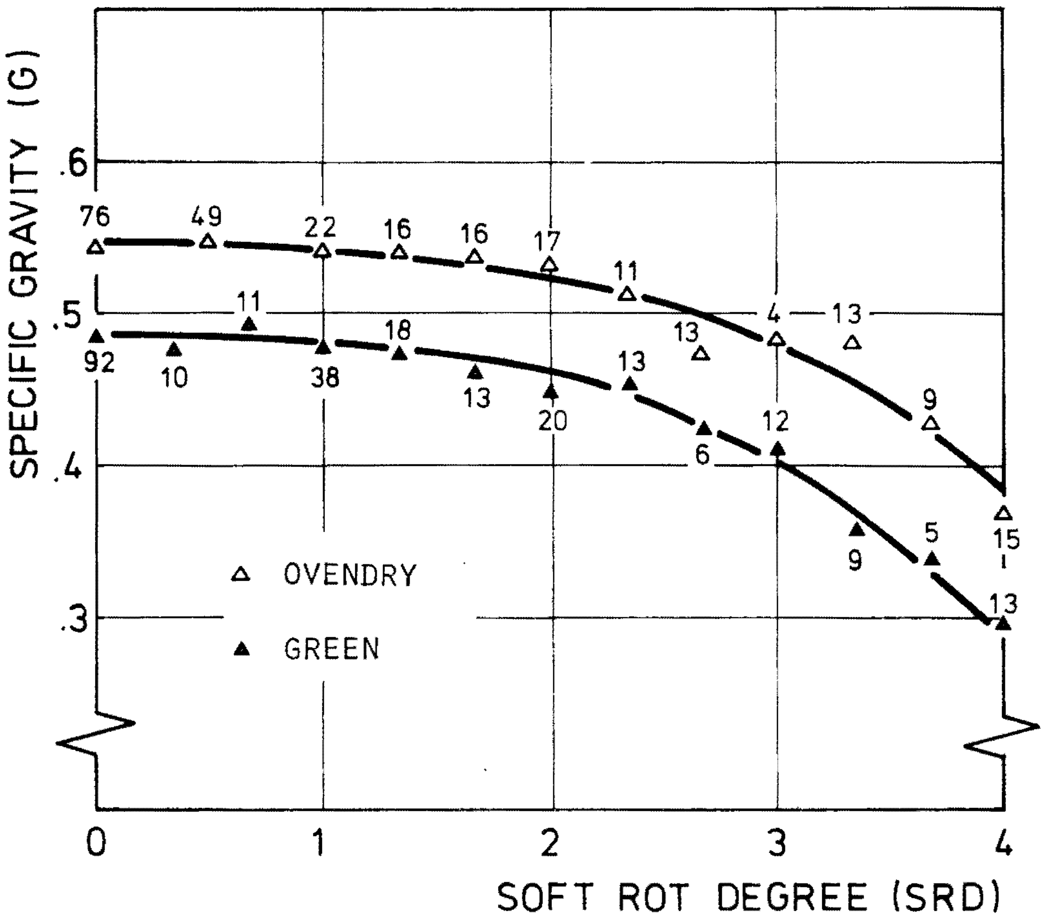


FIG. 17

Relative ultimate stress and relative modulus of elasticity as functions of soft rot degree.

FIG. 18

Regression of soft rot degree on specific gravity



OVENDRY (tension specimens)

$G_O = .546 - .0025\ SRD^3$

CORRELATION = .61

NUMBER OF SPECIMENS = 261

STANDARD ERROR OF ESTIMATE = .059

GREEN (compression specimens)

$G_G = .483 - .0031\ SRD^3$

CORRELATION = .78

NUMBER OF SPECIMENS = 260

STANDARD ERROR OF ESTIMATE = .042

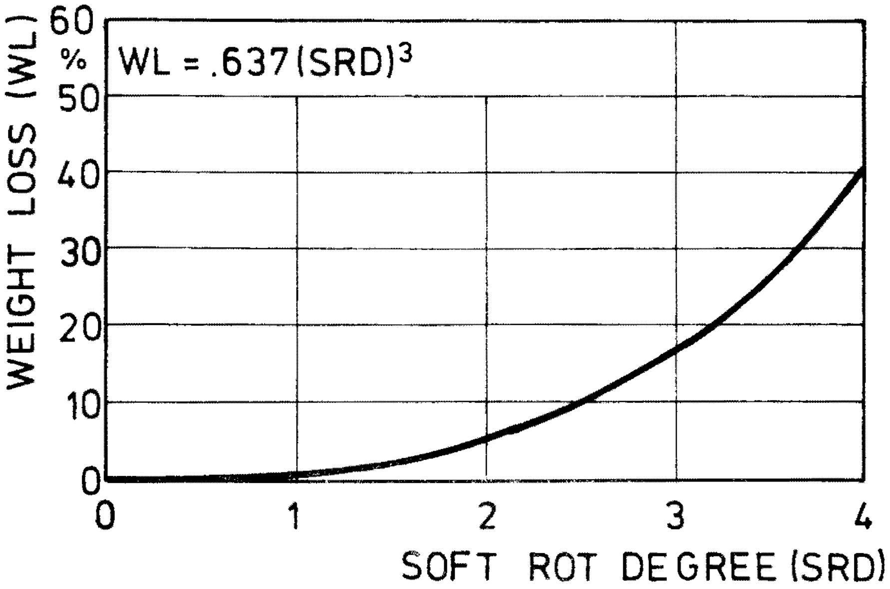


FIGURE 19.
WEIGHT LOSS AS A FUNCTION OF SOFT ROT DEGREE.

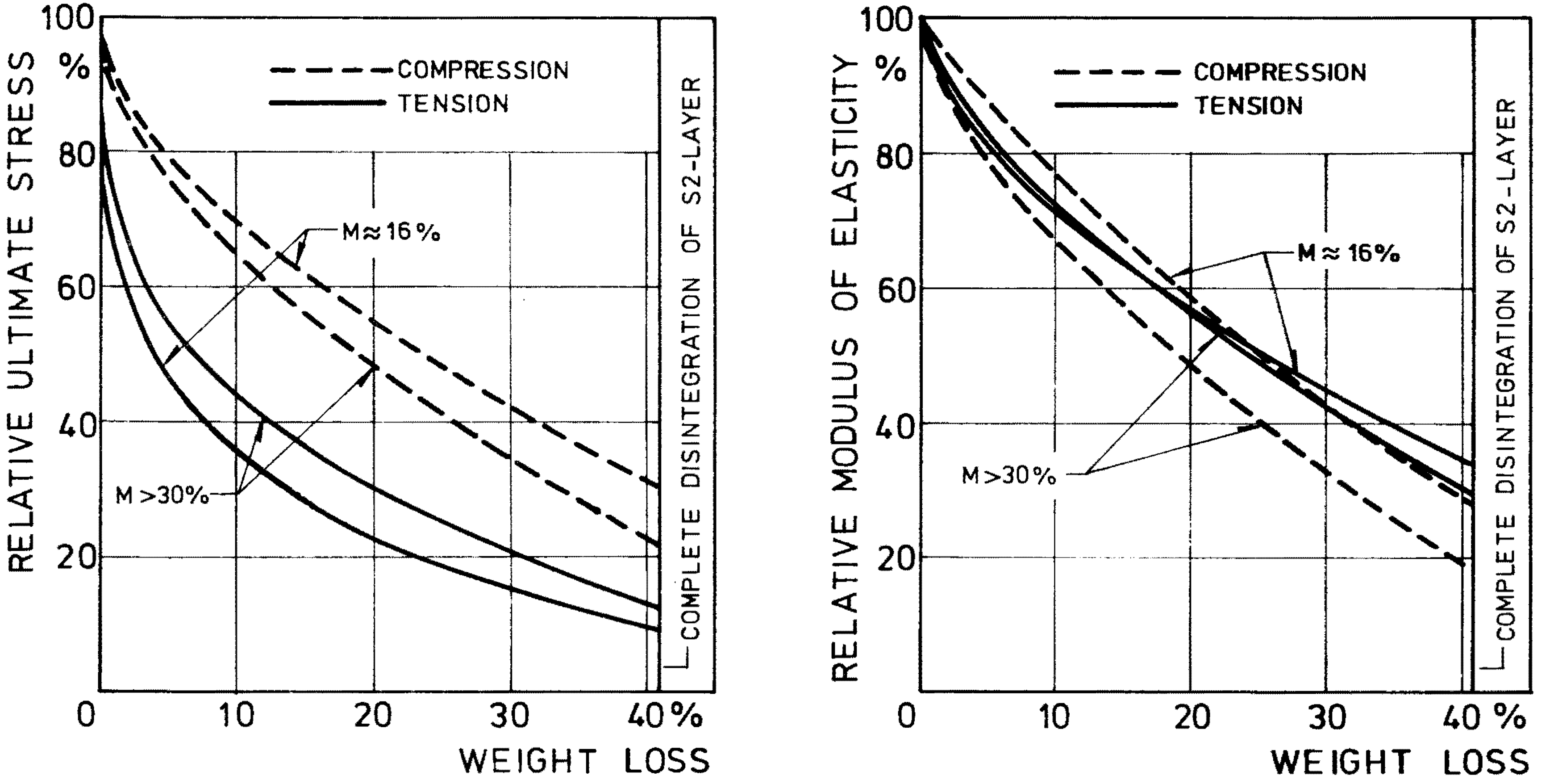


FIG. 20
Relative ultimate stress and relative modulus of elasticity as functions of weight loss.

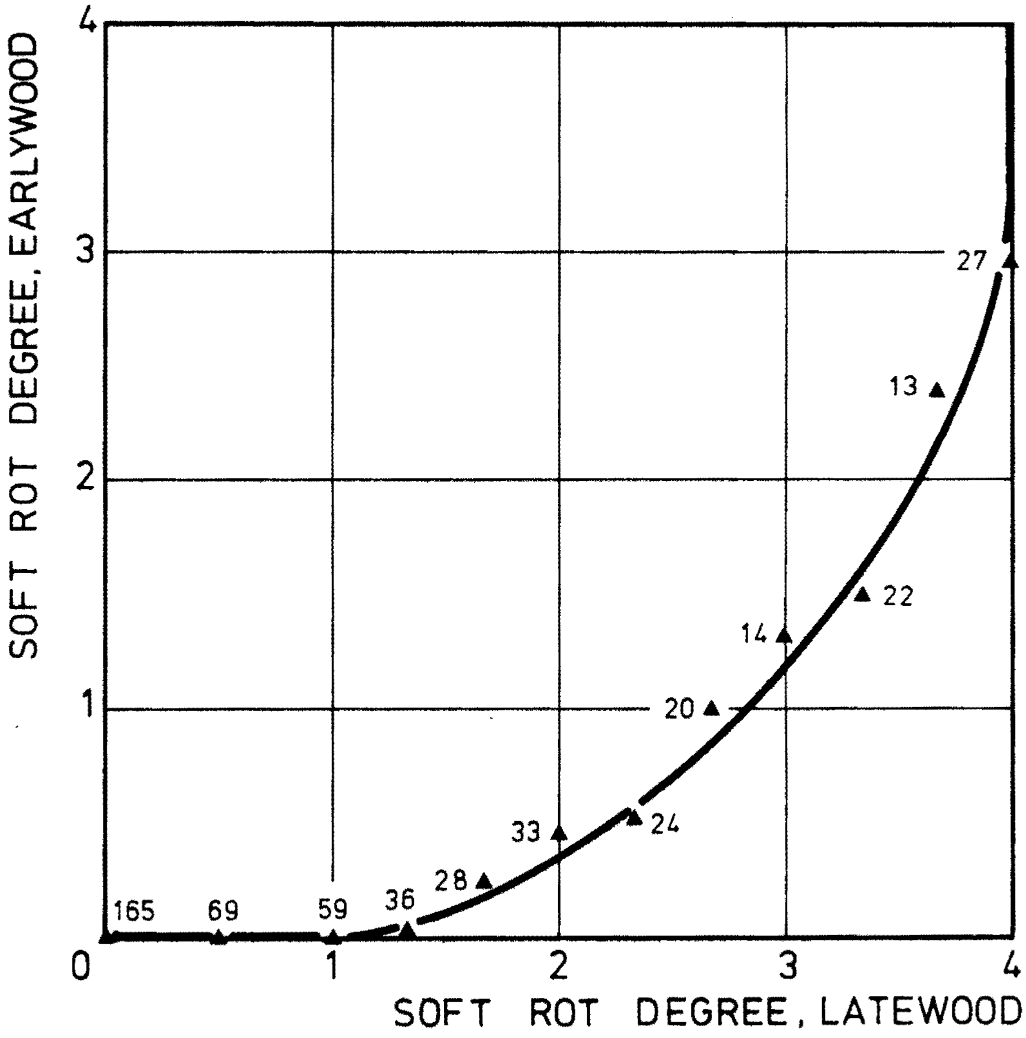
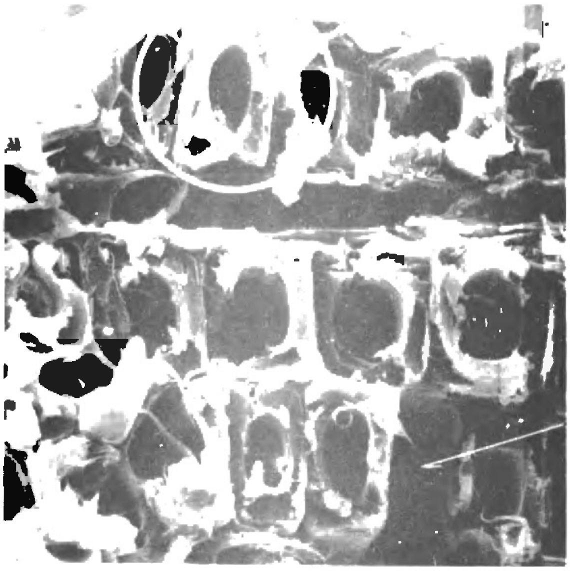


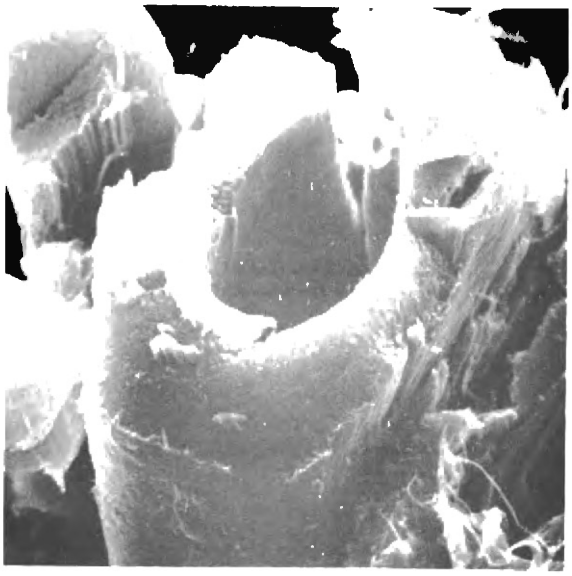
FIG. 21
Diagram illustrating the preferential soft rot decay of latewood cells.



a. x 650

Note a few cavities in cell corners and hyphae in some of the cell lumina.

A latewood cell has been pulled out by a shear failure of the S1/P region.

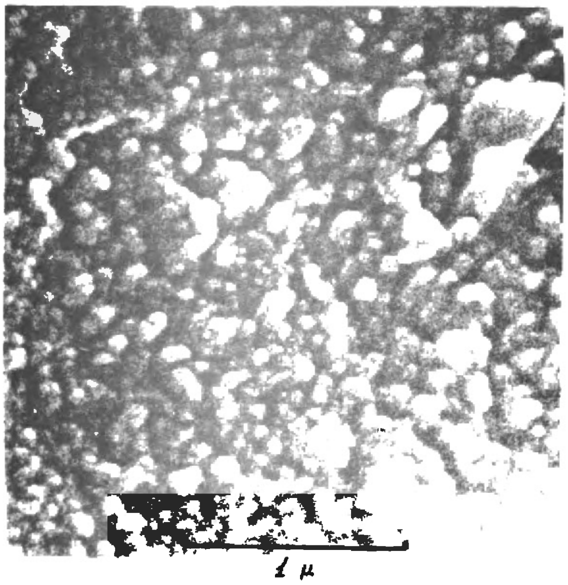


b. x 2.600

Magnification of encircled area of a.

Note the shear failure of the S1/P region and the subsequent failure of S2 leaving a remarkably even surface of fracture.

Note the few sheets of microfibrils sticking up.

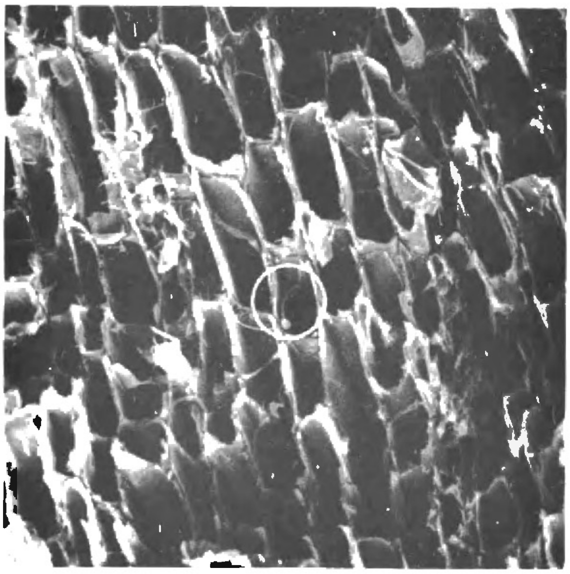


c. x 32.000

Magnification of encircled area of b.

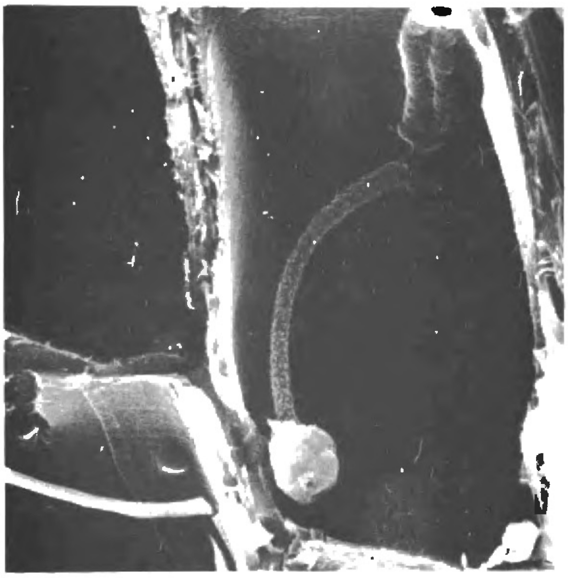
Note the bundles of cohesive-fractured microfibrils.

FIGURE 22. Tensile failure of mildly attacked Scots pine latewood. Scanning micrographs.



a. x 240

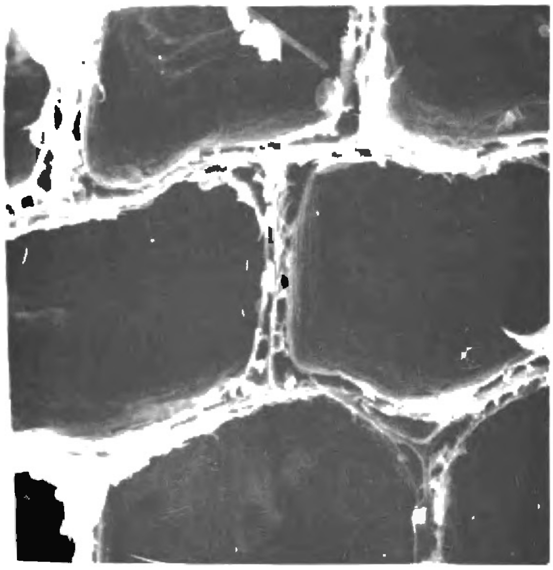
Mildly soft rot decayed earlywood. The surface of fracture is still rather irregular like that of non-decayed wood.



b. x 1.800

Magnification of encircled area of a.

Note how the hypha, after having penetrated the tertiary wall, is growing longitudinally inside the cell wall.

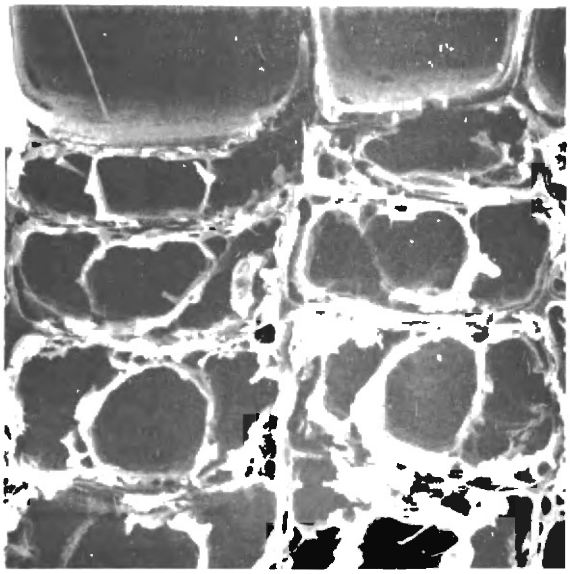


c. x 950

Heavily attacked earlywood.

Note that the surface of fracture is now very even. The S2-layer is almost totally disintegrated, leaving only a skeleton of compound middle lamellae and tertiary walls.

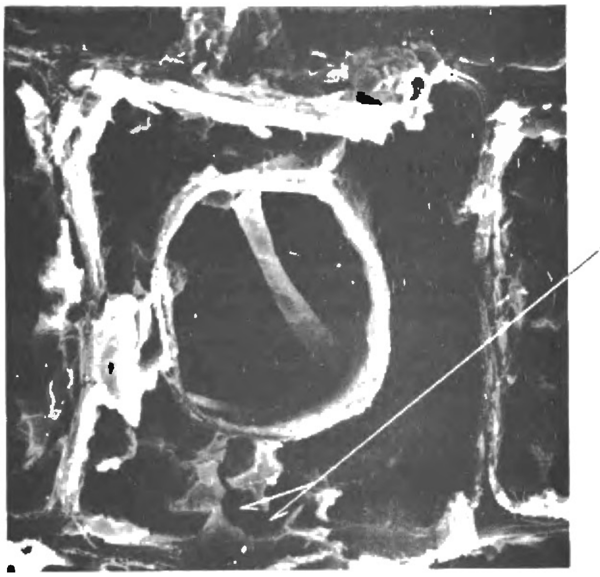
FIGURE 23. Tensile failure of soft rot decayed Scots pine earlywood. Scanning micrographs.



a. x 1.200

Heavily decayed latewood cells.

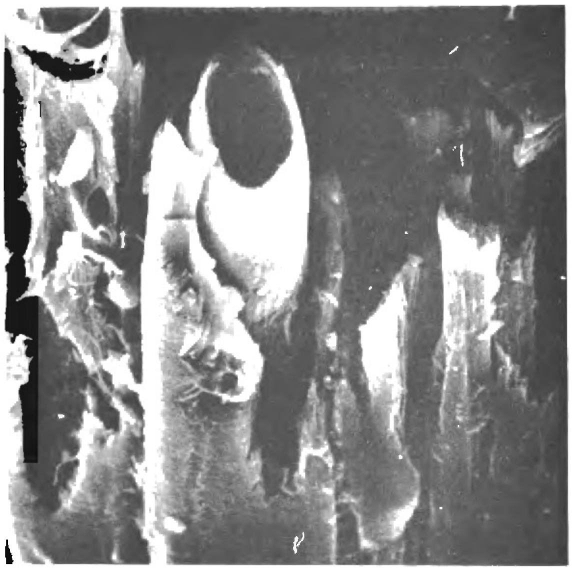
Note that the upper two earlywood cells are only moderately decayed.



b. x 3.000

Heavily decayed latewood cell.

Note the few remaining cavities.



c. x 1.100

Heavily decayed latewood cells.

Note the shear failure of the S1 region , and note the S3 layer forming a hollow cylinder having very little structural contact with the rest of the wood substance.

FIGURE 24. Tensile failure of heavily decayed Scots pine latewood. Scanning micrographs.

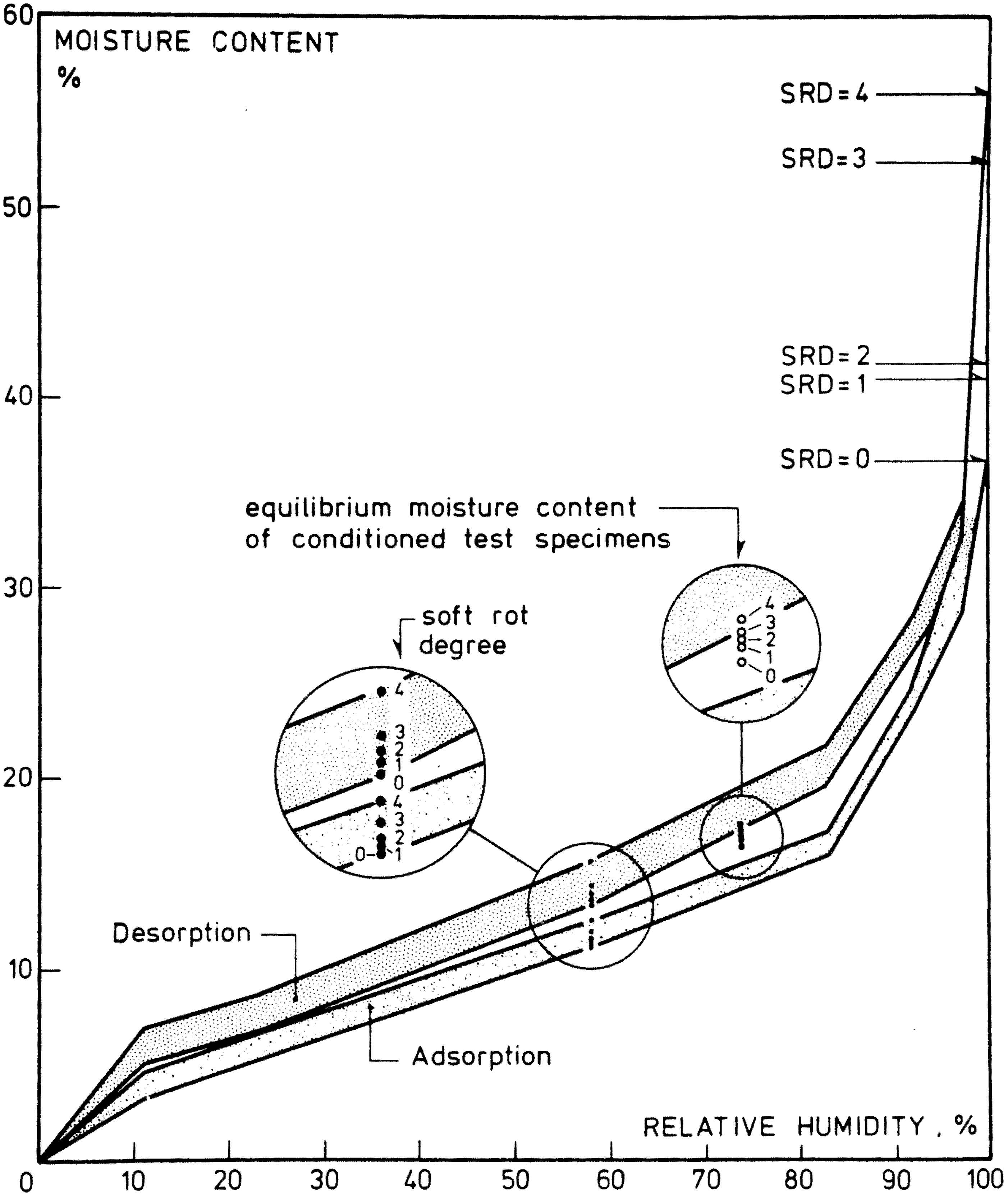


FIG. 25
Sorption isotherms of soft rot decayed wood

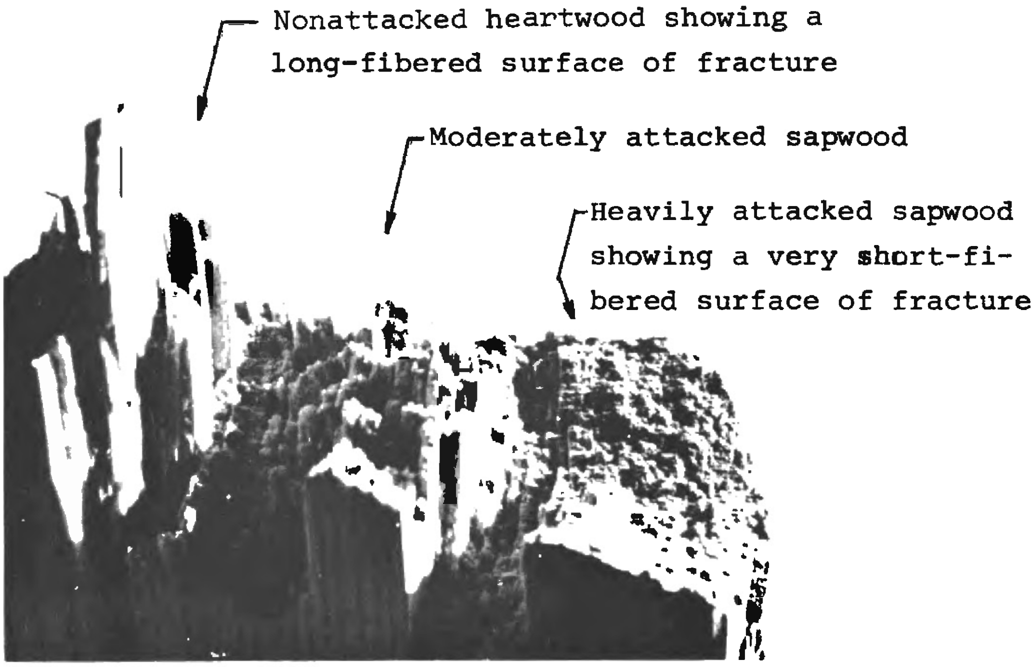


Figure 26. Sector of a soft rot attacked salt-impregnated pole. Tensile failure. x 2.

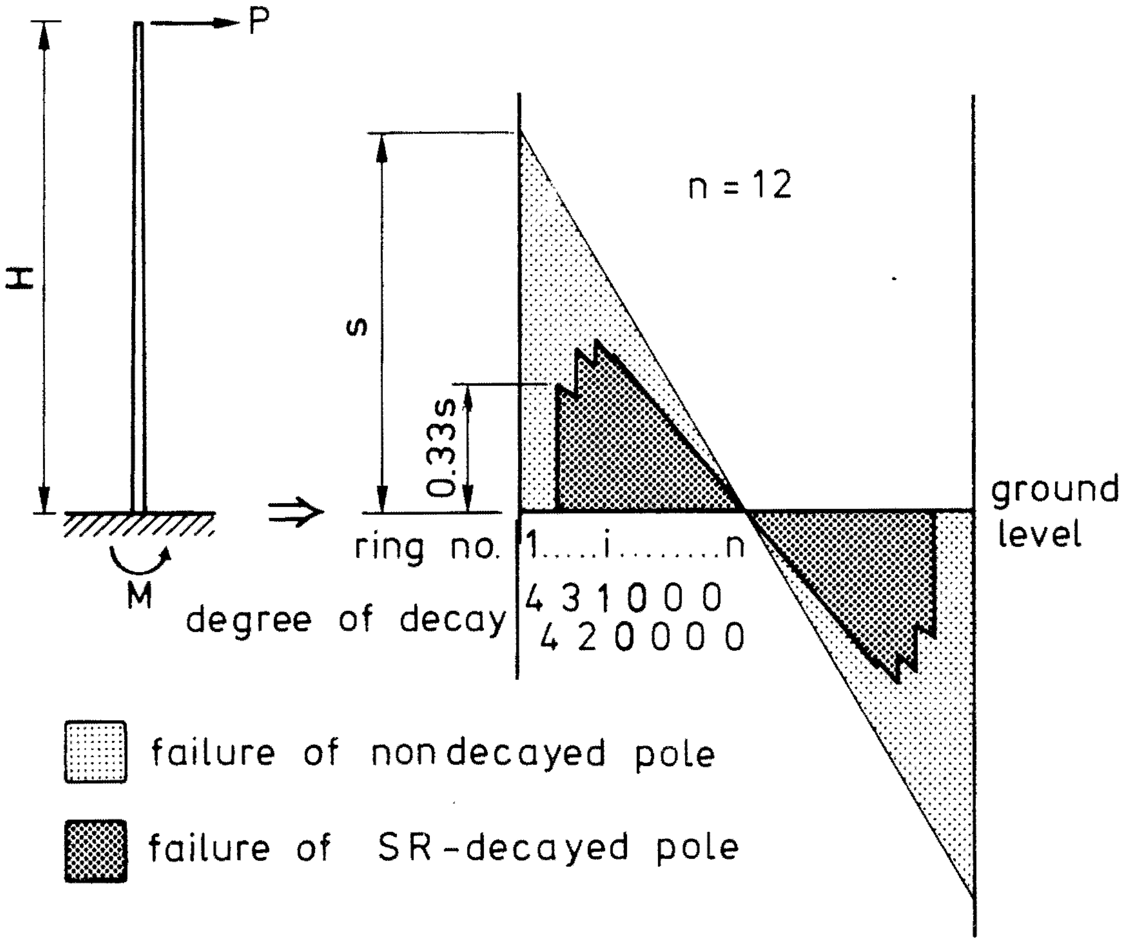


FIG. 27
Example of stress distribution across a ground level cross section of soft rot decayed pole at failure.

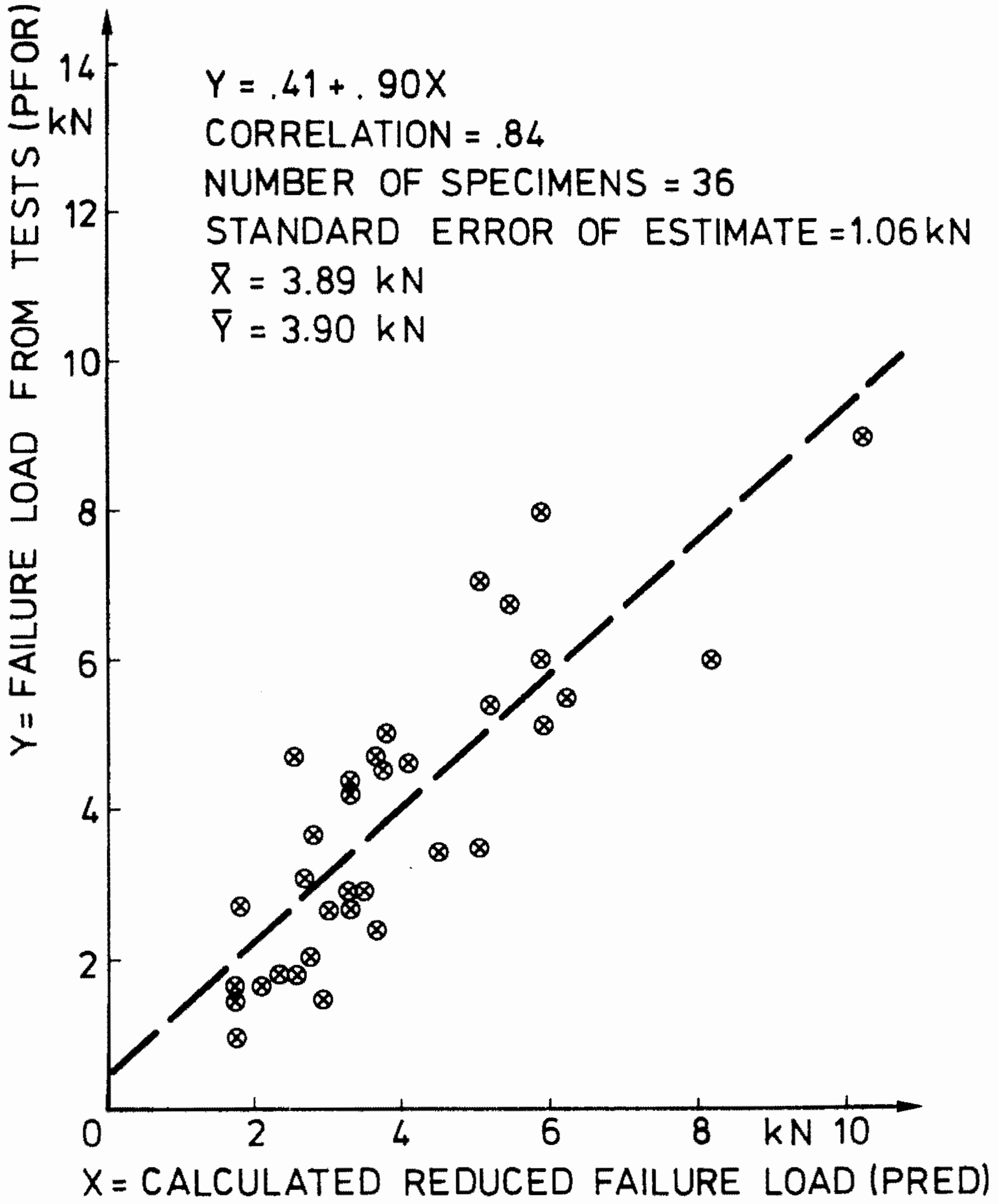


FIGURE 28
REGRESSION OF CALCULATED REDUCED FAILURE LOAD ON FAILURE LOAD FROM TESTS.

3

STUDIES AND EXPERIENCES OF OCCURRENCE AND DEVELOPMENT OF SOFT ROT IN SALT-TREATED POLES OF PINE (*Pinus silvestris*) INSTALLED IN SWEDISH TRANSMISSION-LINES IN THE YEARS 1940-1954

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CONTENTS

INTRODUCTION

Soft rot fungi of the groups *Ascomycetes* and *Fungi imperfecti* form characteristic cavities in the secondary layer of a wood cell wall. The practical significance of the attack of soft rot in salt-treated transmission line poles of Scots pine (*Pinus silvestris*) has, so far, not been ascertained. Nor have any systematical studies of salt-treated poles in various surroundings been reported.

Several authors, in a variety of laboratory tests, have used the weight loss as a criterion for the degree of deterioration of the decaying wood. This, however, implies the knowledge of the initial weight, which is not available for field samples of previously attacked samples. Henningsson (1967), among others, has shown that considerable reduction of the strength properties of wood was found in samples with insignificant losses in weight. Under practical conditions, a gradation of microscopically verified soft rot attacks is an acceptable basis for calculating the remaining mechanical strength. Systematic registration of the presence of soft rot cavities in salt-impregnated poles, in order to calculate the residual strength, has not previously been carried out.

The extent of soft rot attacks in poles of different age and from varying localities has been described by Gersonde and Meyer (1963). The Swedish Wood Preservation Committee published (1970) a diagram showing the degree of decay as a function of the service life of the poles (fig 1).

The present work describes the result of microscopic examinations of some 2,000 borings extracted from 20 to 23-year-old salt-treated poles (Scots pine) from the southern and central parts of Sweden.

The purpose was to map out the occurrence of soft rot in Sweden and its influence on the mechanical strength of the poles as well as to contribute to the development of new and more satisfactory methods for inspection of salt-treated poles. The present work is part of a joint project on soft rot, triggered by alarming results from a series of strength tests carried out by Sydkraft AB (Schmidt and Jacobsson 1976). The following companies and institutions were involved in the project: Sydkraft AB, Svenska Reimpregnerings AB Cobra, the Royal College of Forestry, and the Technical University of Denmark.

SCOPE AND BACKGROUND

Soft rot was first observed microscopically by Schacht (1863), but not until 1954 and later have authors such as Savory (1954), Gersonde and Meyer (1963), Henningsson (1967), Findlay (1970), Lundström 1971 and 1973), Wälchli (1972) and Nilsson (1973 and 1974) described its wood-destroying properties.

The fact that soft rot can invade and destroy preservative-treated poles was shown by, among others, Gersonde and Meyer (1963) who describe the presence of slight, moderate, and heavy soft rot attacks in poles of varying age and type of preservative treatment as well as under different external conditions.

In Sweden, during the war 1940-45, the creosote oil was replaced by the Boliden salts BIS (1940-50), S (1948-52) and S 25 (1952-54). Other salt preservatives such as Basilit U and UA were used to a lesser extent and only for the period 1940-43. In the beginning of the war a considerable number of poles were impregnated by the open tank method, but after 1943 the majority of poles were pressure-impregnated.

The year-marking of the poles was rather deficient during the period 1940-54 and, furthermore, information on the applied preservatives and methods is vague. In this study "salt-treated" poles describe all poles treated with waterborne salt preservatives during the period 1940-54.

The information of the total number of salt-treated poles installed in the electric overhead-grids during 1940-54 is incomplete. The Telecommunication Board gives 1.5 million poles as the number installed in its lines during this period, which is roughly one third of the total number of poles.

The estimated number of poles in Swedish electric power grids today is 10 million, including 3 million salt-treated poles (1940-54); this is presuming that the proportion of salt-treated poles is roughly the same as in the telecommunication grids.

Since 1960 systematic inspections have been carried out by Svenska Reimpregnerings AB Cobra by request of various electricity distributors all over Sweden. The applied method included excavating the pole to the necessary depth, cutting away severely decayed wood, and visually examining the borings. Until 1972 visible external deterioration of the salt-treated poles was almost exclusively the criterion for the decay inspection. Only the spongy, almost totally deteriorated wood was examined and the wood further in from the decayed surface was estimated as sound because of the considerable hardness of the wood in spite of frequent discolouration.

The inspected poles were classified:

1. Sound = No visible attack or discolouration
2. Slight attack = Discoloured surface and/or maximum 5 millimeter depth of deteriorated wood
3. Moderate attack = 5-10 millimeter deep deterioration
4. Heavy attack = More than 10 millimeter deep deterioration

A heavily attacked pole was rejected when more than one third of the crosscut area of the pole was destroyed.

All poles were recorded as to degree of decay and year of installation, provided the poles were year-marked. Statistics were worked out from year to year which in 1969 resulted in the diagram mentioned earlier (fig 1), showing the development of decay in the outer layers of salt-treated poles as a function of service life. The material included some 30,000 year-marked salt-treated poles from all parts of Sweden. The diagram was published by the Swedish Wood Preservation Committee in "Information om träskydd" 1970:1.

As may be deduced from the following, the described inspection method proved insufficient. However, it is important to point out the fact that the very experienced inspectors produced a very stable and concordant judgement of the poles.

In order to check the present guidelines for replacing salt-treated poles, Sydkraft initiated and carried out a series of strength tests in situ of old salt-treated poles in Southern Sweden in 1972 (Schmidt and Jacobsson 1976).

Before the test every pole was inspected according to the old method described above. Paying no attention to the deteriorated outer layer the expected bending strength of the poles was calculated with regard to the remaining diameter. The strength tests showed that in most cases the real failure load was much less than the calculated one. The only possible explanation to this was that the remaining, apparently sound and hard wood, must have been subjected to alterations, which could not be registered by the old inspection methods, and which had led to drastically reduced strength properties of the pole.

A biological and microscopic examination showed that all incorrectly judged poles were attacked by soft rot (Henningsson and Nilsson 1976).

The results from the strength tests were alarming from various points of view:

1. The existing inspection method was insufficient where soft rot was involved.
2. An increasing frequency of broken poles was to be anticipated in the near future, if improved decay inspection and pole replacement were not intensified.
3. The risks of operational disturbances as well as injuries to personnel involved in accidents caused by pole-breaks were greater than imagined.

Consequently, it became an urgent task to develop better inspection methods as well as to map out the occurrence of soft rot in Swedish poles.

At that time microscopy was the only known method for judging a soft rot attack and it was decided to study the development of soft rot in salt-treated poles by the use of microscopic techniques.

Roughly 2,000 borings were collected from salt-treated poles in southern and central Sweden. Samples were collected in Skåne, Öland, Dalsland, Värmland, Dalarna, Medelpad, Hälsingland and Jämtland.

As a rule, one half of the samples came from cultivated land and the other half from woodland or other types of land. Moreover, an equal distribution between high- and low voltage poles was sought, whereby different pole diameters were included in the material.

The borings were taken from the pole's most decayed part which was located by the use of a hatcher. Difficulties arose, however, during the initial sampling in December 1972, when many poles were frozen. Furthermore, the sampling technique was still under development and, therefore, the most decayed part was probably not always found.

MATERIALS AND METHODS

The boring samples were kept in suitable plastic tubes which were properly marked for later identification. An initial attempt to judge the soft rot attack by visual examination proved to be too uncertain.

Each boring was registered in a record (fig 2). Before the microscopic examination, the boring samples were wetted and the cross-sections were coloured with saffranin. A light microscope with magnifications of 150x, 300x and 600x was used.

Although cavities in the earlywood were observed and to a certain degree gradated, it was mainly the degree of soft rot in cross-sections of latewood cells which was recorded through the microscope, since the latewood cells are decisive for the mechanical strength of the wood. In order to describe the observations, a 0-3 degree scale was employed. Eventually this scale was extended to 0-4 degrees, which can be described as follows:

0 = No cavities
1 = Few cavities
2 = Several cavities isolated from each other. Original cellular structure intact.
3 = The cellular structure still intact; cavities abound, dominating the area and fusing into pairs or clusters. Isolated remnants of the secondary cell walls are still visible.
4 = The many cavities have now fused and the secondary wall, as a whole is dissolved. Of the original cell wall only the S_1 and S_3 layers and the middle lamellae are left. The latter appear under the microscope as a light pattern on the background of the dark mass of deteriorated cell walls.

The distribution of the soft rot cavities in the cross-section of the secondary wall has been calculated for the different degrees of soft rot as shown in table 1.

Table 1.

Degree of soft rot	Cavities, % of cross-section of secondary cell wall
1	1 - 10
2	10 - 40
3	40 - 90
4	90 - 100

A cross-section from each centimeter of the borings was examined microscopically. The examination was done continuously from the surface to the centre and was terminated only when no more cavities were found. Soft rot gradation and other observations were recorded (fig 2).

A clearly arranged statistical account of the recorded soft rot values was complicated by the many parameters which were expected to influence the progression of the soft rot.

A computer program was made in which these parameters were included. The coding form is shown in figure 4. The results of the microscopic examination were converted to one figure expressing the residual strength in per cent of the initial strength for each pole (Hoffmeyer 1976).

The material is still too limited (1,200 samples) to cover the many parameters, but interesting results can be expected as the material increases. In the present work the program has been employed for conversion of "The old diagram" (fig 1) to the present system for soft rot gradation. Computerized results of the microscopic examination may prove useful for random checks of poles. Furthermore, the program is intended for scientific use for analyzing results from microscopic examinations.

RESULTS AND DISCUSSION

General

The decay which as late as 1972 was classified as external decay in salt-treated poles may now almost without exception be named soft rot. However, a limited amount of the so-called "orange rot" has been recorded since 1960 and has recently shown increasing frequency (Schmidt and Jacobsson 1976, Wälchli 1973).

Conversion of old inspection norms into the soft rot gradation system

The diagram (fig 1) refers to approximately 30,000 year-marked salt-treated poles, inspected for decay and recorded during 1959-68 according to the old method described on page 3.3.

The diagram shows the biological deterioration of an average Swedish salt-treated pole from 1940-54 as a function of the service life (15-30 years).

It is true, we now know, that the old inspection method is obsolete with regard to soft rot. It was, however, consistent and uniform before. In order to throw light on the important phenomenon of aging by means of our present knowledge of soft rot, combined with the extensive material mentioned from the diagram (fig 1), a conversion of the old values into new ones has been made.

Borings were taken from 200 salt-treated poles which previously were inspected according to the old system,
100 poles of the category "Moderate attack" and
100 poles of the category "Heavy attack"

Two samples were taken from each pole and the ground level diameter was measured. The samples were examined under the microscope and the average soft rot equivalents to "moderate attack" and to "heavy attack" were calculated and plotted according to the graphs in fig. 5 and fig. 6.

Table 2.

Degree of soft rot	Average strength reduction, %
0	0
1	23
2	45
3	67
4	88

By using Hoffmeyer's (1976) average values for strength reduction (table 2) the reduced bending strength corresponding to a moderately and heavily attacked pole was calculated. The calculation was done for four different and characteristic ground level diameters. By means of the values from fig 5 as well as the percentage distribution of moderate and heavy attacks from fig 1, the reduction in bending strength as a function of service life for the above-mentioned pole diameters was calculated. The result is shown in a diagram (fig 7).

The material from fig 1 originates from 10 kV and low-voltage poles, with mean ground level diameters of 230 and 200 mm respectively. As the geographical centre for the material lies along an east-west line through Stockholm, one has to consider higher values, south, and lower values, north of this line. For practical reasons the "slight" attack has been disregarded which means that the real situation is worse than is shown in the diagram. By means of the "aging" diagram (fig. 7), one could deduct the point of time for the first inspection as well as maximum intervals between the inspections in order to keep operational and personal risks on a reasonable level.

The significance of the ground level diameter of poles for the soft rot development

It has previously been assumed that soft rot develops as fast in a thick pole as in a thin one. That this assumption is correct is apparent from table 3, which shows the average diameter reduction (caused by soft rot) in millimeters for 661 poles mainly from 1946 in cultivated soil in Småland. All the poles were examined during 1974 according to the poking-method.

Table 3. Average diameter reduction in poles with different groundline diameter. (661 poles in cultivated soil in Småland).

	Diameter, mm									
	190	200	210	220	230	240	250	260	270	280
No. of poles	50	71	131	134	90	86	55	26	11	7
Diameter reduction mm	49	53	48	51	51	48	53	46	59	52

Influences by various factors on the soft rot development

Many years' experiences from field work has shown that decay develops faster in poles in cultivated farmland than in other surroundings such as woodland, moors, etc. In table 4 the result is shown from an inspection of 790 poles in Småland standing in cultivated soil, woodland and moorland.

The cause of the very marked differences may be found in the fungi's need for water, oxygen and nourishment.

Swedish poles are usually supported by a backfill of rock, and as long as the backfill is clean it will drain and ventilate the ground part of the pole, but as soon as the spaces between the rocks are filled with top soil, leaves etc. the decay will start directly below the air-soil level. The deeper the air-soil level is below the ground line, the poorer the environment is for the growth of the fungi.

On farmland the use of various fertilizers may accelerate the growth of the soft rot fungi.

Poles with a backfill of soil and poles with a backfill of rock mixed

Table 4. Average diameter reduction in mm for salt-treated poles in various surroundings. All poles were inspected during 1974 with the poking method. All poles belonged to the same grid in Småland.

Environment	Year	No. of poles	Average diameter, mm	Average diameter reduction, mm
Cultivated soil	1944	101	230	43
	1945	81	226	58
	1946	101	222	50
Sum		283	226	49
Woodland	1944	106	236	19
	1945	152	226	25
	1946	89	223	21
Sum		347	228	22
Moor	1944	33	233	15
	1945	46	224	14
	1946	81	220	14
Sum		160	224	14

with top soil show the main attack 5-15 cm below the ground line. The more open the stonefill, the further down the main attack. This may explain the common but erroneous perception that a thick pole rots slower than a thin one. The big pole is often surrounded by much bigger rocks than the small pole and is thus better protected against earth-packing. The soil-contact for a big pole very often occurs on a considerably lower level where nourishment is poorer.

Practical experiences from a very large number of inspected poles show that the maximum attack for poles of 200-250 mm diameter was found between the ground-level and 40 cm below it, whereas the maximum attack in poles of 300-400 mm diameter was reached as far down as the 95 cm level.

In poles standing in clear water year round the soft rot develops very slowly or not at all below the water-level. On the other hand several soft rot attacks have been detected in the pole 30-50 cm above the permanent water-level, more or less on the level where the water absorption from below is balanced by the evaporation from the surface of the pole.

Observations concerning soft rot in heartwood and earlywood

In the present work no determinations of the heartwood limits have been done. However, the general impression from the microscopy is that soft rot occurs also in the heartwood but only when the sapwood is heavily attacked.

In the earlywood the soft rot cavities occur later than in the latewood, the difference being 1 to 2 soft rot degrees.

Zone division of Sweden according to frequency of fatal soft rot attacks

The empirical material from microscopic and field inspections has been summarized in a map (fig 8) where the country has been divided into 4 zones with characteristic rejection percentages for the salt-treated poles from 1940-54.

Of course such a division is very summary. It is hoped, however, that the map will prove useful as a guide for the pole owners.

The poking method

With microscopy and the grading of soft rot as controlling factors, a German method described by Sorsa (1973) was tested for decay inspection of salt-treated poles. Called the "poking method", it is based on the fact that soft rot attacked wood breaks more easily than sound wood. While the fracture of sound wood shows long, pointed and sharp spikes, the fracture of soft rot attacked wood is abrupt, glassy and lacking in sharp spikes.

In the poking method a sharp, pointed instrument, for example an awl, is pressed into the pole and bits of wood are dug out perpendicular to the direction of fibres. Where sound wood splinters reluctantly and with a crackling sound into long, sharp spikes, the damaged wood will come out willingly in square blocks and with a muffled sound (fig 9).

During the education of the inspectors in the poking method, borings for microscopic examination were continuously taken for comparison. It soon appeared that soft rot attacks of the degrees 4 to 2 were found with reasonable certainty by the skilled inspectors.

This is confirmed by the results from Sydkraft's strength tests where the poking method was used for the calculation of the residual strength (Schmidt and Jacobsson 1976).

In its present form the poking method is practiced as follows:

1. The pole is excavated all around and to a necessary depth which means at least 20 cm below ground level for soil packed poles or below the air-soil level for poles with backfill of rock.
2. With a suitable hammer the softest spot of the pole is found and here the poking operation is carried out (fig 9).
3. When the inspector has poked so deeply into the pole that sound wood (with normal tensile strength) is found, the hole depth is measured and the same operation is carried out on the opposite side of the pole.
4. Original ground line diameter is measured and recorded together with the found diameter reduction which is the sum of the two hole-depths.

A natural objection to this method is that wood which is not totally destroyed is discounted, namely wood of the soft rot degrees 1, 2, and to some extent, 3. All of these have still some residual strength left. This error must, however, be accepted as contributing to the personnel security and service reliability of the lines.

The poking method was brought into practical use in 1973 and approximately 25,000 salt-treated poles have been inspected since then.

As expected, the frequency of rejected poles has considerably increased in comparison with the results of the old method (Schmidt and Jacobsson 1976).

Experience shows that one requirement for a uniform inspection is that inspectors regularly send in borings for microscopic examination. The microscopic results are compared with the inspectors' results, and necessary adjustments to the operation can be made.

The moisture content of the pole influences the inspection. The strength of a dry pole could be 30-40 % higher than the strength of the same pole under wet conditions, and in this connection routine control with the microscope is of the utmost importance for the quality of the inspection.

The poking method is time consuming and presupposes a trained staff. In order to improve the safety of the personnel working on the poles, experiments have been carried out (under current microscopic control) with an instrument which, in a fast and simple way and in the hand of more or less unskilled persons, reveals if a pole is dangerous or not. These experiments have now been concluded with very satisfactory results.

GENERAL

The present work is intended as a contribution to the exposure of the soft rot problems in the Swedish over-head lines, not only with special regard for the personnel safety, but also with an eye to other practical consequences for service reliability, inspection work in general, and, of course, economy.

SUMMARY

More than 4 million 20-35 year-old salt-impregnated - mainly BIS-salt - poles of Scots pine (*Pinus silvestris*) are included in the Swedish electricity transmission and telecommunication grids. The majority of these poles are attacked by soft rot. The soft rot fungi belong to *Ascomycetes* and *Fungi imperfecti* are the limiting factor for the service life of salt-treated poles.

Due to the heavy soft rot attack a considerable number of the salt-

treated poles do not meet the security standards of this country, and thus represent an obvious, potential danger both to the lines and the line-workers.

Approximately 100,000 salt-treated poles were inspected for decay during the period 1959-1972 by a method which is now in soft rot terms considered obsolete.

Since 1972, approximately 2,000 borings were collected and studied microscopically. Also, 25,000 salt-treated poles were inspected by a new method which has turned out to be a great improvement.

The present work deals with the results and practical experience of the above mentioned work concerning the occurrence and development of soft rot in Swedish salt impregnated poles from the period 1940-1954.

It is shown that:

1. Verifying of the soft rot attack by means of visual examination of the borings has been insufficient.
2. Systematic microscopic gradation and registration of the occurrence and the extent of the soft rot cavities in the secondary walls of the latewood cells of the poles has been performed and accounted for, with the objective of relating the observations to the reduced strength properties of the poles.
3. The normal soft rot attack is initiated from the surface of the pole, just beneath ground-leve and with gradually decreasing severity, horizontally as well as vertically.
4. The soft rot initiated reduction in bending strength of an average 15 to 30 year-old pole was shown to be of the magnitude of 4 per cent per year.
5. The development of soft rot was not shown to be significantly dependent on the pole's ground line dimension.
6. The soft rot deterioration was faster in the poles in cultivated soil than in forestland; it was also faster in earth-packed poles than in stone-packed ones.
7. A geographical division of Sweden with regard to soft rot occurrence and intensity is introduced.
8. A new pole inspection method is described.

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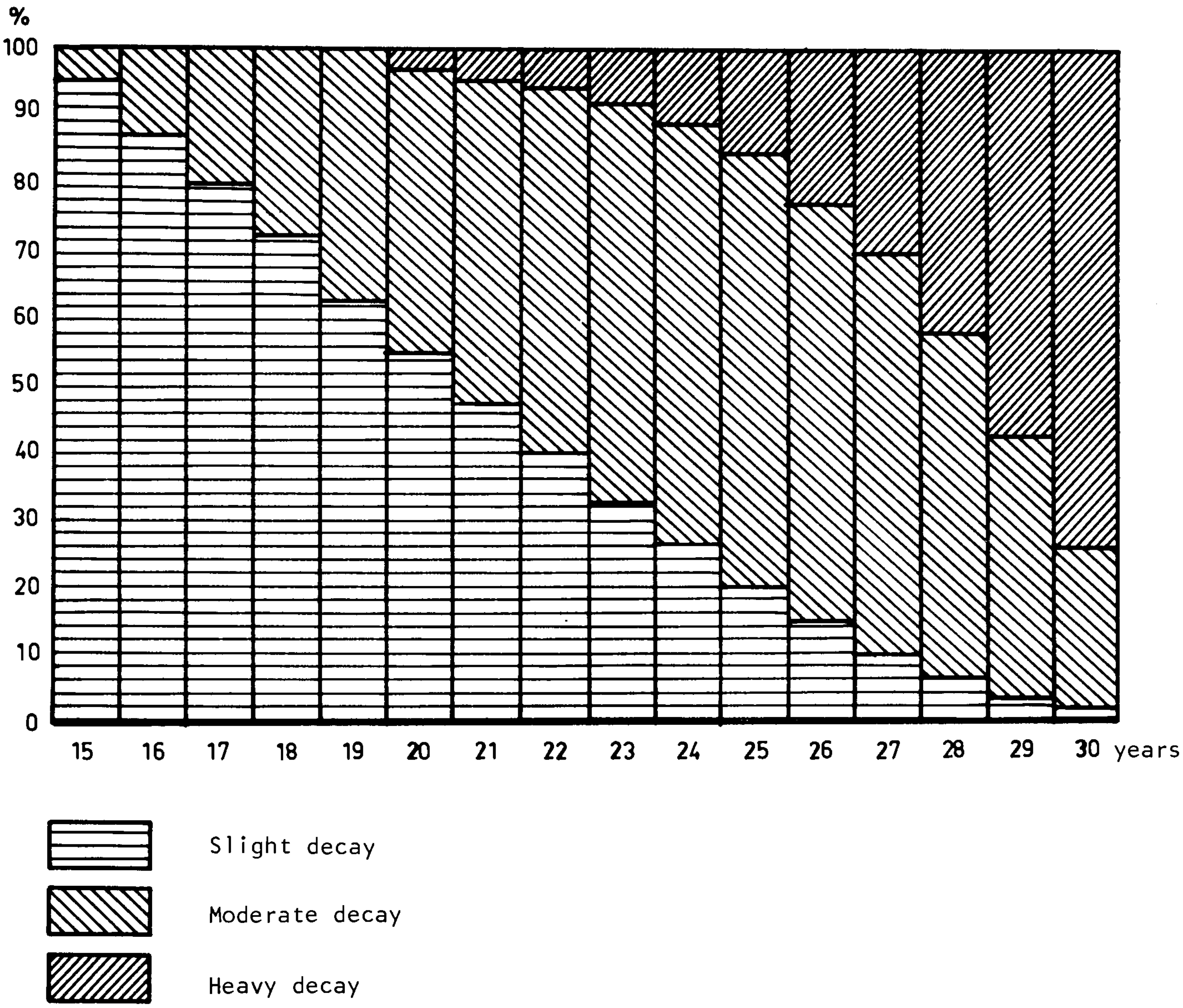
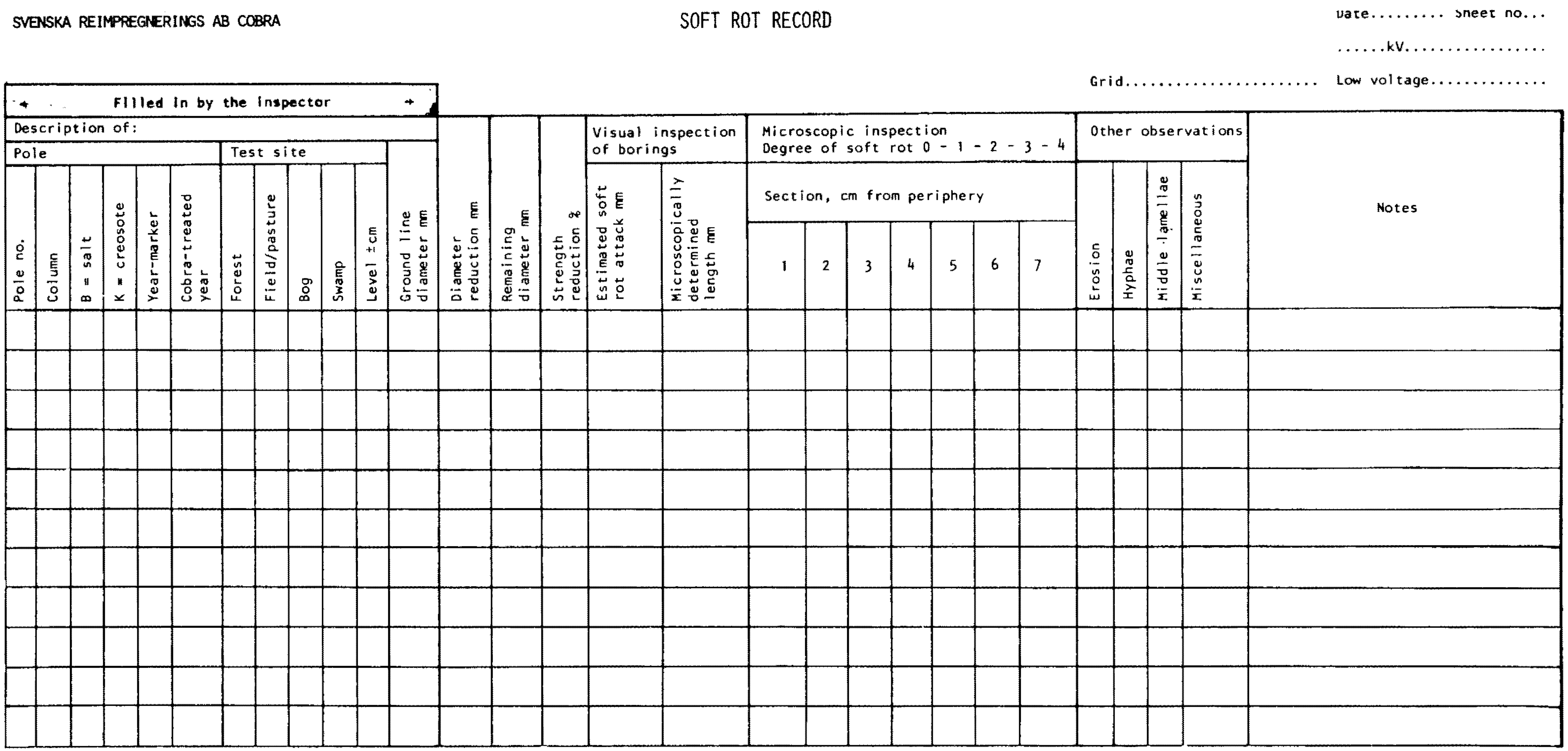


Fig 1. Soft rot decay as a function of service life for approximately 30,000 salt-treated poles, inspected in the period 1959 - 1963 according to older methods.



SVENSKA REIMPREGNERINGS AB COBRA

SOFT ROT RECORD

Date......... Sheet no...
......kV................
Grid...................... Low voltage.............

← Filled in by the inspector →																												
Description of:												Diameter reduction mm	Remaining diameter mm	Strength reduction %	Visual inspection of borings		Microscopic inspection Degree of soft rot 0 - 1 - 2 - 3 - 4							Other observations				Notes
Pole						Test site					Ground line diameter mm				Estimated soft rot attack mm	Microscopically determined length mm	Section, cm from periphery							Erosion	Hyphae	Middle lamellae	Miscellaneous	
Pole no.	Column	B = salt	K = creosote	Year-marker	Cobra-treated year	Forest	Field/pasture	Bog	Swamp	Level ±cm							1	2	3	4	5	6	7					

Fig 2. Form for microscopic examination.

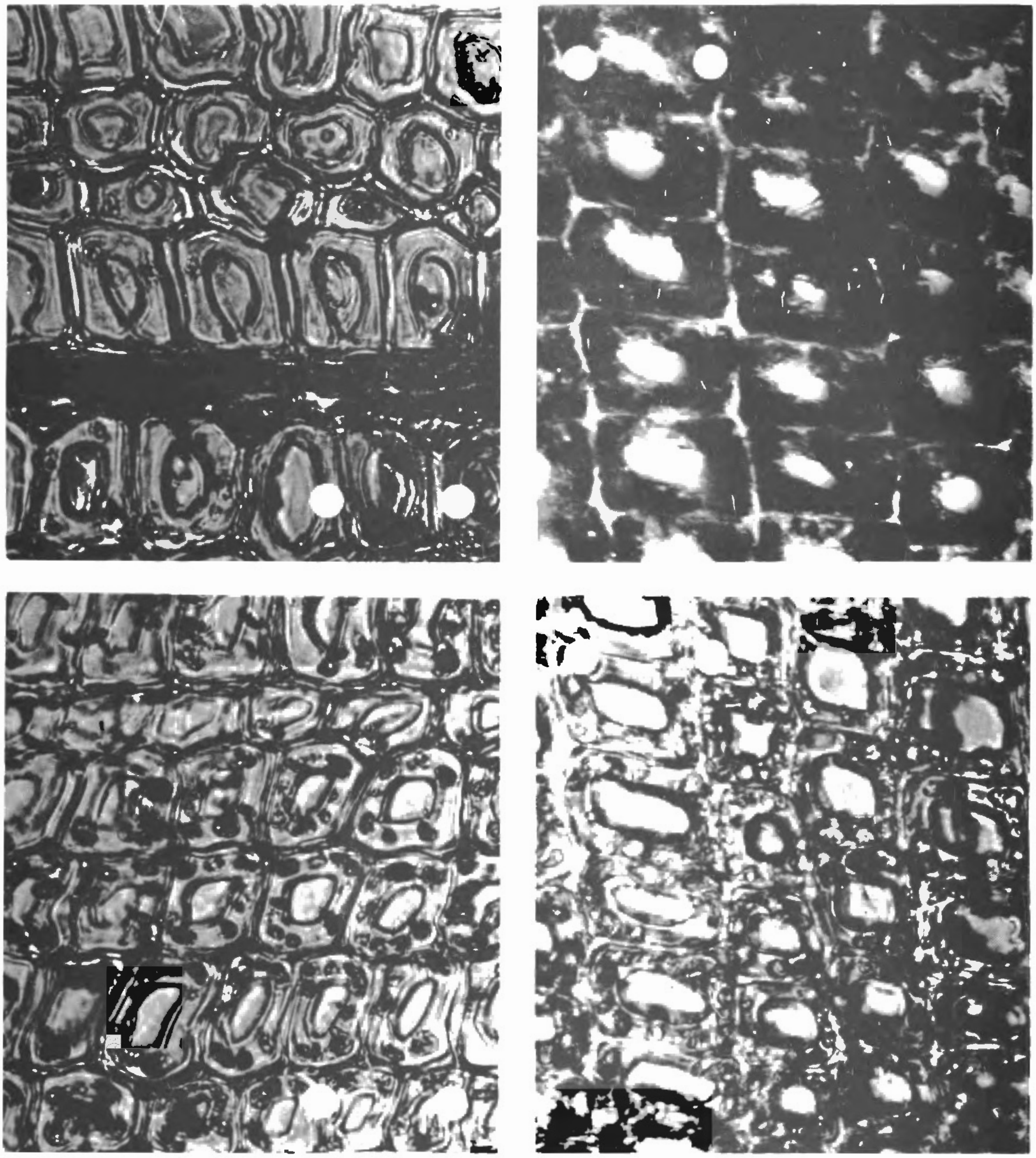


Fig 3. Micrographs from soft rot attacked poles showing the degrees of soft rot. 1. upper left, 2. bottom left, 3. bottom right and 4. upper right. Photo Preben Hoffmeyer

POLE INSPECTION

Company	Date			Voltage	Line No.	Pole No.	Column No.	Preservative treatment	Year	Age	Type of reimpregnation	Reimpregnation, year	Type of land	Level		Original diameter mm	Diameter reduction mm	Remaining diameter mm	Radius reduction mm		Remaining strength kp	Reduc = remaining strength, %	Microscopic inspection Degree of soft rot 0 4 Cm from periphery										Width of annual rings	Erosion	Middle lamellae	Hyphae	Bacteria	White rot	Brown rot	Orange rot	Optical changes	Culture results	Notes		Degree of soft rot	Sampling site
	Year	Month	Year											+	cm								1	2	3	4	5	6	7	8	9	10														
1 2 3	4 5	6 7	8 9	10 11 12	13 14 15 16	17 18 19 20	21	22	23 24	25	26	27 28	29	30	31 32	33 34 35	36 37 38	39 40 41	42 43 44	45 46 47	48 49 50 51	52 53 54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76 77 78	79	80

VOLTAGE

000 = Telephone
001 = Low voltage
010 = 10 kV
Etc.

COLUMN NO.

Blank = Only one column

PRESERVATIVE TREATMENT

0 = No preservative treatment
1 = Creosote
2 = Salt preservatives before 1954
3 = K33 after 1955
4 = Other salt preservatives
8 = Osmosis
9 = Brushing

AGE

1 = Creosote > 30
Salt > 20 years
2 = 20-30
15-20 years respertively
3 = < 20
< 15 years respectively

REIMPREGNATION

1 = Cobra
2 = Wolman-bandage

TYPE OF LAND

1 = Cultivated land/Pasture
2 = Forest
3 = Bog
4 = Water

WIDTH OF ANNUAL RINGS

1 = Very thin
2 = Normal
3 = Very thick

EROSION

0 = Not investigated
1 = None
2 = Slight
3 = Moderate
4 = Strong

MIDDLE LAMELLAE ATTACKS

0 = Not investigated
1 = None
2 = Slight
3 = Apparent
4 = Heavy

HYPHAE

0 = Not investigated
1 = None
2 = Few
3 = Many

BACTERIA

0 = Not investigated
1 = None
2 = Few
3 = Many

DECAY

0 = Not investigated
1 = None
2 = Doubtful
3 = Apparent

OPTICAL CHANGES

0 = Not investigated
1 = None
2 = Slight
3 = Apparent

CULTURE TEST

0 = None
1 = Done

NOTES

0 = No further action
1 = Follow-up measures taken

SR-GRADATION

1 = Code 0 - 3
2 = Code 0 - 4

SAMPLING

1 = One sample
2 = Two samples, weakest
3 = Two samples, not weakest
4 = Three samples

Fig 4. Coding form for computer program for the registration and recalculation of microscopic observations.

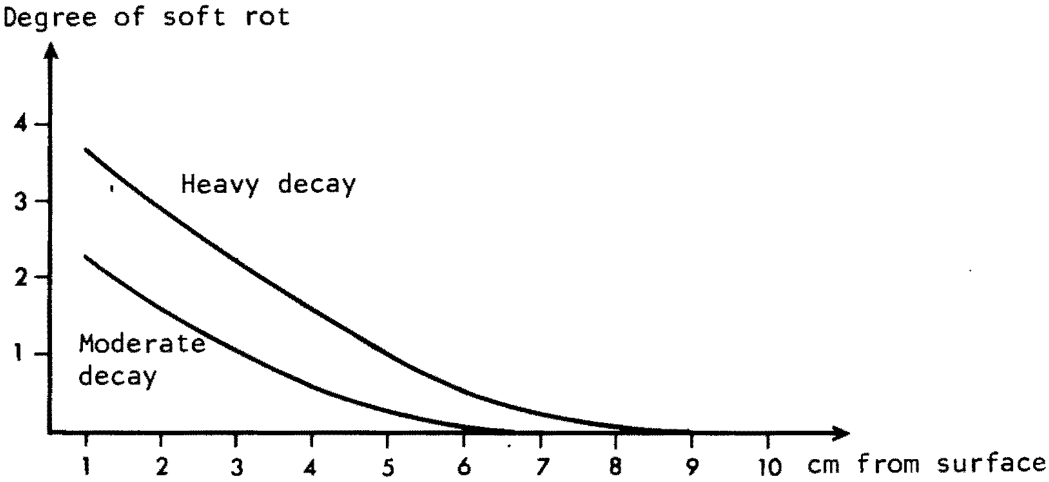


Fig 5. Moderate decay and heavy decay according to the old inspection system expressed in degrees of soft rot.

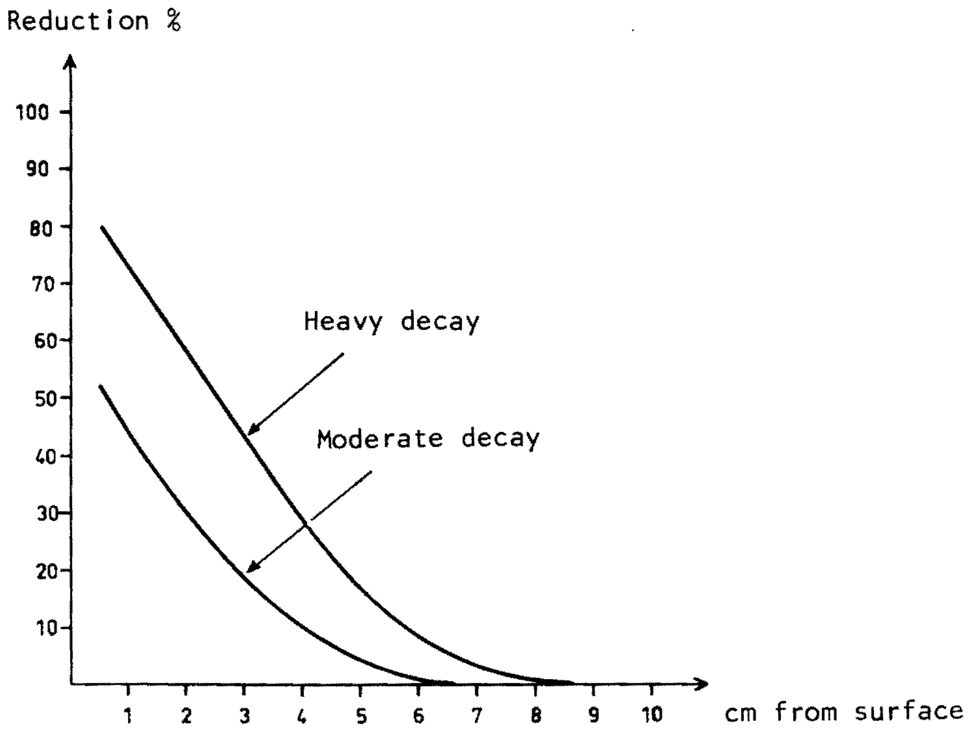


Fig 6. Moderate decay and heavy decay according to the old inspection system expressed as percent reduction of the bending strength.

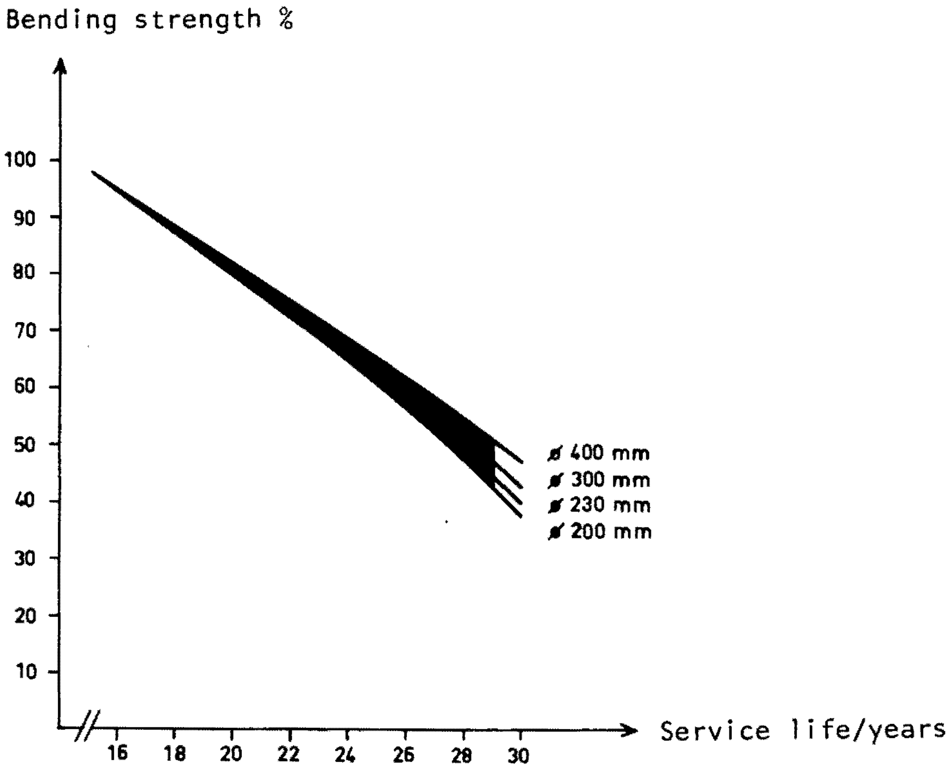


Fig 7. The bending strength of the poles as a function of service life. Following ground line diameters are represented: 200, 230, 300 and 400 mm.

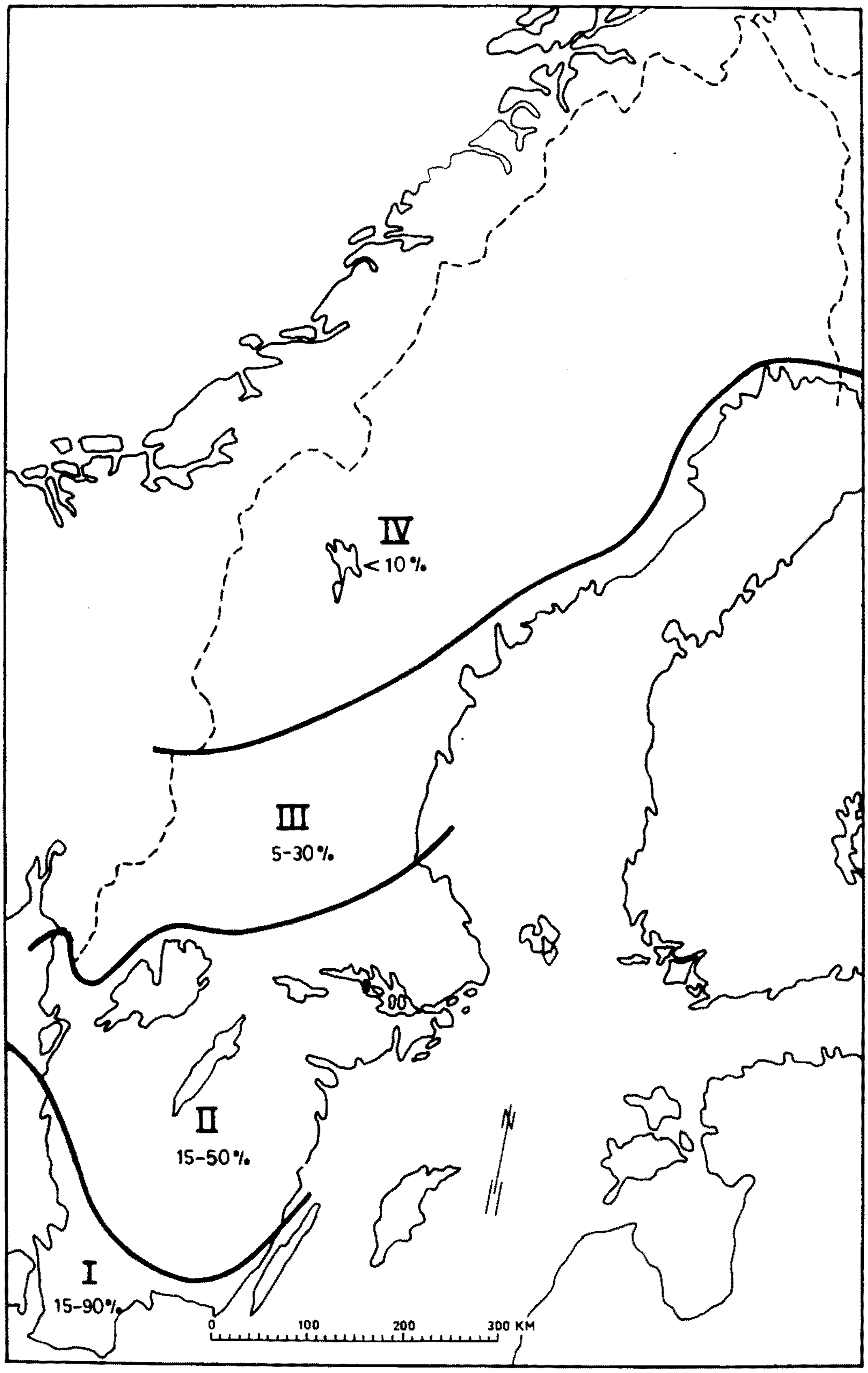
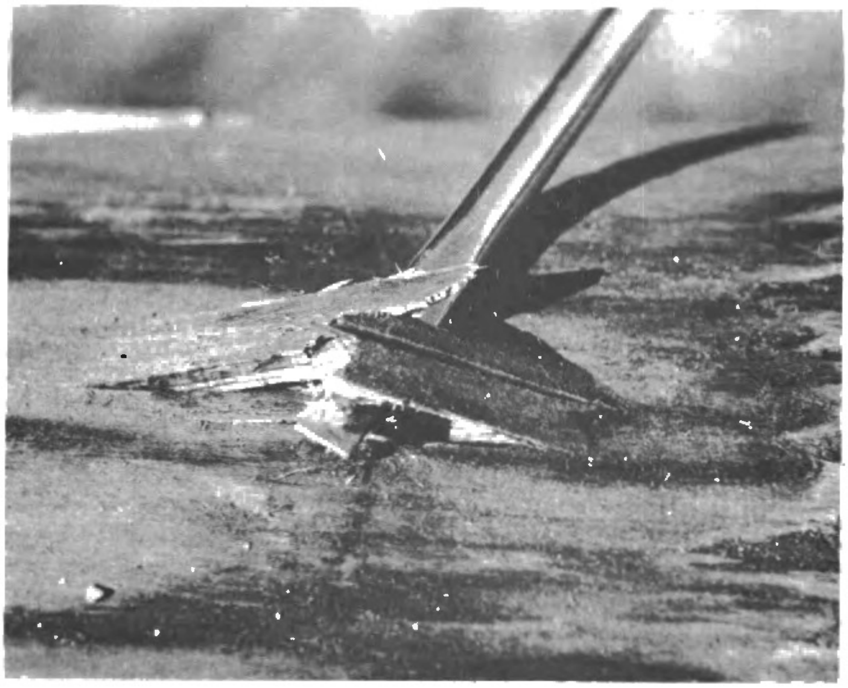
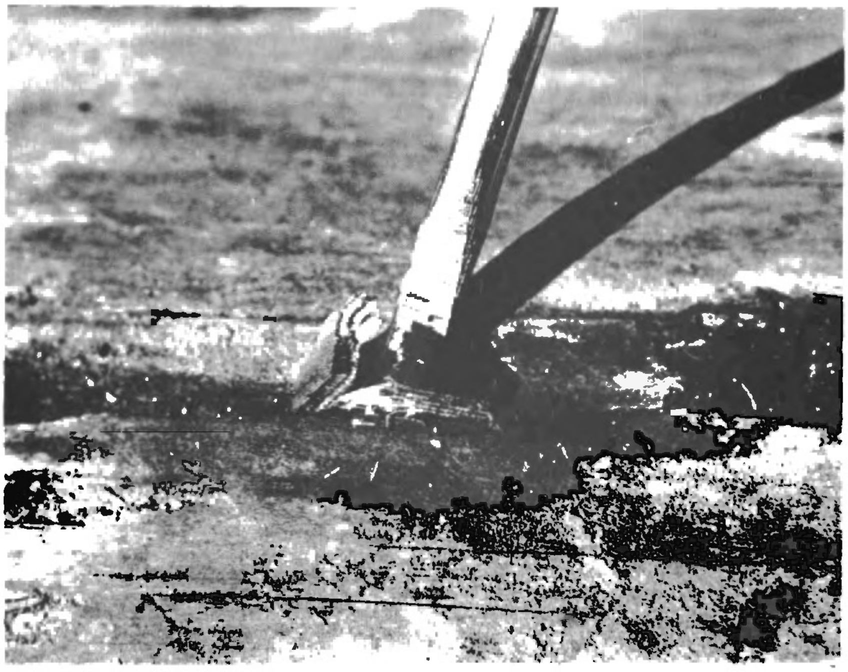


Fig 8. Southern limits for various percentages of rejected salt-treated poles (20 - 35 years old). The poles were installed in the period 1940 - 1954.



A



B

Fig 9. Typical fractures when using the "poking method".
A. sound wood B. soft rot attacked wood.
Photo Kai R Spangenberg

4

EXPERIENCES OF SOFT ROT DAMAGES IN SALT-TREATED TRANSMISSION POLES OF PINE WITH SPECIAL REFERENCE TO THE RESIDUAL STRENGTH OF DAMAGED POLES AND INSPECTION METHODS

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CONTENTS

INTRODUCTION

Within those areas of southern Sweden where Sydkraft is responsible for the distribution of electricity there are about 700,000 poles, nearly all pressure impregnated. Pressure treated poles came into use at Sydkraft in the mid-twenties. Before, only untreated, mainly oak, poles were used.

Until the outbreak of the second world war almost all poles were treated with creosote oil. As the war made import of creosote oil impossible, Sydkraft, as well as other companies, began to use poles treated with different salt preservatives. In the beginning both Basilit U and UA and Boliden BIS were used, the former being abandoned after a few years. *All poles will be referred to here as salt-treated poles, regardless of the salt preservative used.*

When creosote oil became available again after the war the practice of treating the poles with creosote was resumed and is still in force today.

During the war 125-150,000 salt-treated poles most of them treated with Boliden BIS, were installed in the distribution grids. This number has now decreased to about 100,000, mainly due to elimination in connection with reconstructions.

A few have been rejected at regular inspections. There are relatively fewer salt-treated poles at Sydkraft than at other electricity companies in Sweden.

As a point in time has now been reached when the mean age of the poles is half of the estimated service life, consideration must be made for an annual replacement of about 700,000/50 poles, where 50 years is the estimated average service life. Consequently, every year about 14,000 poles would have to be replaced because of decay. This assumes, however, that over the last 50 years roughly the same number of poles has been installed each year.

The annual costs for replacement would be Skr 8-10 million (1974) and these figures show that the costs for maintenance of wooden poles are appreciable.

The value of having well trained inspectors can therefore hardly be over estimated. They must be able to judge when a pole is to be replaced according to personnel safety, operational safety and optimal economy.

The first inspection is generally done when the poles are about 20 years old. Thereafter, inspections are scheduled at 6 to 10-year intervals. When examining a pole, the inspector must take into consideration that a nonreplaced pole has to remain standing with enough strength for another 6 to 10 years.

This activity, important from both safety and economic points of view, has previously been neglected. Often, persons with little or no education on decay and its influence on the strength properties of the poles have been responsible for the inspections and, moreover, uniform rules for pole replacement have not been available.

In 1970 a forced inspection of all the poles was initiated. Being aware of the age of the salt-treated poles, grids containing large numbers of these were favoured. Another reason for this was that at earlier inspections these poles had never been properly bared below the ground level to provide an opportunity to discover any serious damage.

After three years of inspections, done mainly by contractor, it was decided to check the reliability of the gradually changing guidelines for judging and replacing poles. During these three years about 20,000 creosote-treated poles were inspected. In 1972 a series of strength tests on poles started. Previously, the poles were inspected and strength calculated. It was soon found that the mode in practice for inspection and regulations for rejection were not acceptable. It was obvious that creosote-treated poles so far had been replaced much too early and salt-treated poles much too late. The strength tests therefore have continued parallel with the development of a new mode of inspection.

An interesting feature of the strength tests was the discovery of a considerable reduction in strength of timber attacked by soft rot (SR) without complete decay.

The experiences from the strength tests and the search for a more reliable mode of inspection could be of interest to others, and therefore the results and ideas arising from this study are presented here.

As pointed out earlier, both creosote- and salt-treated poles have been strength tested. The tests of the creosote-treated poles are not yet finished so only the results from the strength tests of the salt-treated poles are shown here.

POLE LINE INSPECTION, FAILURE LOAD CALCULATION AND STRENGTH TESTS

Before every series of strength tests the salt-treated poles have been uncovered to a depth of about 50 cm and inspected by presently known methods. Based on those inspections the failure loads have been calculated. How the strength tests were arranged can be seen in appendix 1. For every pole a record was made according to appendix 2. The results from all strength tests are shown in appendix 3.

Following inspection, calculation of the failure load for the pole was made based upon the presupposed ultimate stress for pine of 50 N/mm^2 at bending, i.e. a safety factor of 2.4 according to the Swedish Standard SEN 3601.

This ultimate stress often is smaller for sound poles and the original failure load can vary considerably from pole to pole. As the original failure load of a pole is unknown, relatively large marginal errors must be accepted comparing calculated data and data from tests.

In appendix 3 the degree of soft rot attack is divided into four groups; 1 is little attack and 4 is completely decayed timber.

Test series A

The poles were inspected using an axe. After determining where the pole was softest, the outer totally decayed layer was removed and the diameter reduction was measured. Consequently, one assumed that the hard core inside the soft outer layer was sound. By virtue of the diameters registered before and after removal of decayed wood the original failure load according to SEN 3601 was calculated, and finally the failure load after cutting was determined.

The results from this series were very discouraging. Obviously the method of inspection had serious deficiencies as no attention was paid to the strength reduction in wood which was attacked by soft rot but not completely decayed.

Upon inspection, badly SR attacked poles were still resistant to impact but hardly any tensile strength remained. The fractures were abrupt, contrasting very much to the fracture of sound wood. No visible damage on the heartwood was observed.

The fracture surfaces of badly SR attacked sapwood were almost completely black, at least when the pole was wet. A typical fracture surface of an SR attacked pole is shown in appendix 4, fig 1. Compared with a characteristic fracture of a decayed creosoted pole, fig 2.

Studying the record one will find that only one third of the poles were inspected in a satisfactory way. This fraction consisted of poles with moderate SR attack and therefore had high failure loads. At that moment only slightly attacked poles could be inspected properly.

Test series B

The above mentioned black fracture surface of SR attacked timber initiated the use of borings to try to determine the degree of soft rot. Before this series the poles were inspected in the same way as in test series A, but with one difference: a visual estimation was made of borings from the most infested part of the pole.

The results from this test series were somewhat more encouraging when actual failure load was compared with the failure load based on the visual estimation of the borings. One now might think that a reliable method of inspection had been found. However, a visual inspection of borings turned out to be quite hazardous, particularly if the poles were wet. During sampling before the strength test the poles were very wet. It will be seen from the record that one serious mistake was made and that the remaining 11 poles were estimated to be less SR attacked than they later turned out to be.

The "axing" method once again was useless. It can only be applied to a slightly SR attacked pole.

Test series C

At the examination before this series no attention was paid to the removed layer. In addition to a visual inspection of borings a microscopic survey was done in some cases. The SR attacks were estimated centimetre for centimetre in the pole according to a certain scale (Friis-Hansen 1976). A new method, "poking", was introduced. It is carried out with a pointed tool, e.g. a heavy-duty awl, which is sunk into the pole to a certain depth where the fibres are tough and continuous. The poking test is carried out at the softest area of the pole which, as for the borings, is discerned by use of an axe.

The difficulty with this method is determination of the depth of which poking should cease. The method seems to be rather rough; with serious SR attacks the pole can be penetrated to a fair depth, leaving a wide entrance hole. This does not matter, however, as the timber under study is almost completely destroyed. In general, the most decayed area of the pole is found first and the depth of the damage is determined. The procedure is repeated on the opposite side of the pole. The calculation of the failure load is based on these two measurements. The direction of the strength test is chosen so that the most decayed side of the pole will be subjected to tensile load.

Upon inspection before this series of strength tests the poles were all very dry and it was difficult to form a judgement about them, from the visual inspection of borings as well as from the poking. The uncertainty was confirmed by the study of results from the strength tests which differed too much from the calculated values. The poking method, however, turned out to be better than the visual inspections of the borings, as can be easily seen from the record.

The method of microscopic inspections of borings, where each centimetre of SR attacked timber was classed with regard to the degree of decay with different reduction in strength and where a total calculation of the failure load of the pole was done, has proved to be almost acceptable. Basis for calculation of residual strength at different degrees of soft rot is shown in another paper (Hoffmeyer 1976). As can be easily understood, this method can not be used practically at the regular inspections. On the other hand random checks can be made of inspectors' judgements to promote uniformity in the reports.

Test series D

Besides the inspection methods mentioned above another method has been introduced here, namely a special instrument (still under development). The method looks promising. It has the advantage of being fast and it could also be used by people who know little about decay.

The differences between calculated and actual failure load are acceptable with all three inspection methods used here. Both the "poking method" and the "instrument method" could be improved. However, rather large distribution must be accepted due to estimation difficulties of the timber and variations in strength in new as well as old poles at different water content.

EXPERIENCES FROM INSPECTIONS IN RECENT YEARS

The strength tests and comprehensive inspections have resulted in the following experiences.

The brown rot and white rot, so common in many other connections, only rarely occurred and did not seem to play any important role for the service life of the pole. The most important factor in this case was soft rot and another type of rot, at present called "orange rot". Experiences from microbiological, microscopic and chemical studies are presented in another paper (Henningsson and Nilsson 1976).

Soft rot occurs sooner or later in all salt-treated poles within the scope of the authors' experience. It is always found at ground level, the most severe decay just below ground level. How far below depends on the presence of rock backfill and its existing condition.

A well made and well kept backfill of rock gives no contact between pole and surrounding soil and provides a certain degree of ventilation in the hole. The worst decay in this case will be found where the pole is directly in contact with soil. If there is no backfill of rock at all or where the hole has been filled with soil, the decay is generally found 0-15 cm below ground level. This is always true for cultivated ground where the soil is in contact with the pole. Consequently, the poles must be unearthed if a proper inspection is to be done.

To be able to estimate the need to excavate around the base of the poles a special inspection of 700 poles has been done where the most severe decay was recorded in relation to the ground level. One half of the poles were from cultivated ground; the rest from woodland, swamp etc. See the following table.

	Site of the most severe decay, cm below ground level								Total no.
	0	5	10	15	20	25	30	40	
Poles; cultivated land	240	11	44	9	3	1	1	1	310
Poles; woodland etc.	123	26	143	63	18	7	2	1	383

Note. The poles were uncovered to a depth of 50 cm.

As can be seen, the worst decay was found at the 15-20 cm level in the case of cultivated land and 25-30 cm level in the case of woodland in almost 100 % of the poles.

In the salt-treated pole the soft rot always appears in the sapwood and then advances in towards the heartwood. In the creosote-treated pole, on the other hand, the decay usually occurs in the sapwood layer close to the heartwood and then advances outwards and often inwards as well. From the strength tests of approximately 30-year-old poles it appeared that the heartwood was always sound.

Severe soft rot attacks occur at an early stage in poles on cultivated ground where the backfill of rock usually is covered with soil and the soil itself favours the development of fungi as does the nitrogen in fertilizers. The service life of a pole on cultivated ground, therefore, is reduced drastically. A control of approx. 3,400 salt-treated poles in southern Småland showed that 55 % of poles on cultivated ground and 15 % of poles on other ground were rejected. In southern Skåne on very fertile ground, there has been a rejection of 85 %.

It is not yet possible to calculate the rate at which a soft rot attack advances in a pole since these problems have been under study for only a few years. This lack of knowledge is serious as it is necessary to know how fast the decay advances in order to be able to predict the service life of a pole and its replacement date. It has been estimated that 8 years is a normal interval between the inspections, but due to uncertainty a sampling test control after four or five years is being considered to see if the assumptions on the rate of decay have been correct. It may be of great value for the future if poles in different types of soil are inspected regularly with reference to the rate of decay. These inspections are not of particular interest for Sydkraft whose poles have an average age of 30 years and will be replaced within 10 years but are for companies with many poles treated early with modern salt preservatives.

Soft rot attacks finally lead to complete softening and decay of the wood. Before that, different degrees of soft rot attack occur which proportionally reduce the mechanical properties of the wood. Relatively advanced SR attack does not seem to influence the hardness to any great extent. As mentioned above, the soft rot advances inwards in a salt-treated pole. As bending strength is proportional to the cube of the pole diameter, a slight reduction of the diameter will cause a serious reduction in bending strength(for example the ultimate stress for a pole whose original diameter (ground line) 230 mm is reduced to 200 mm by soft rot decay, decreases to 65 %).

The so-called "orange rot", mentioned earlier seems to become more and more abundant in the old poles. At an inspection of approximately 3,000 poles in southern Småland it was present in 120 poles (4 %). This type of decay may increase with the age of the poles. It has appeared in poles all types of soil to about the same extent. Once orange rot has infested a pole, it soon causes complete decay of the sapwood. Characteristic of a well developed orange rot is that within a very thin outer crust, all sapwood is decayed. No heartwood has been attacked as far as these studies have shown. The decay is easily observed if the soil is removed from around the base of the pole. This type of decay has been found at varying depths from the ground line to 30 cm below, i.e. on the same level as soft rot. A photograph of orange rot is shown in appendix 4.

During the inspections it was noticed that the poles originally were over dimensioned. That has made a delay in replacement possible. Today's dimensioning of salt-treated poles for transmission lines is a dubious practice. It can hardly be an advantage to be as close to the minimum limit as is actual today. A safety margin, e.g. 20 mm, should be added to the standard diameter, which is usually done in the dimensioning of steel poles for use in ground contact. The additional costs are moderate and the measures could also be useful for future reinforcements which are quite common for transmission grids.

OPERATIONAL AND PERSONNEL SAFETY

Sydkraft, as well as other companies, at present has many soft rot attacked poles from the 1940s. Many of them are so decayed that the remaining strength is contributed by the strength of the heartwood only where the diameter varies from pole to pole. This should initiate a strongly intensified inspection of salt-treated poles from this period.

Until all poles have been correctly inspected an enhanced number of interruptions in the electricity distribution must be anticipated when the poles for different reasons are subjected to high loads. To add a safety margin to poles at road crossings etc. seems reasonable.

Seriously decayed poles are dangerous for operators working with them. It is the operators' duty, however, to ensure that the pole is not too decayed and all line operators have to know how an inspection is to be carried out. These demands are hard to fulfill and other ways must be chosen to guarantee safety. During the strength tests failure loads were not found to be so small that there would be any risk for a man to work on the pole unless it was subjected to a unidirectional force. Therefore, these old salt-treated poles from the 1940s must not be subjected to any unidirectional force during operation unless the pole is braced. This must be done not only when cutting a power cable or installing a service but also when there are high wind forces perpendicular to the line. The work will be more complicated and take longer time than before and special stay wires must be designed to be a part of the safety equipment.

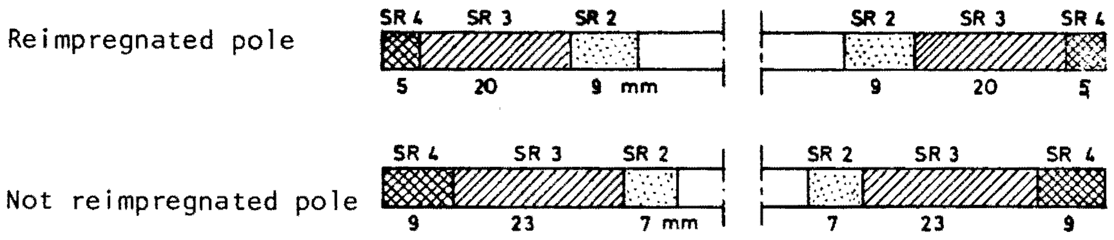
An enhanced number of accidents due to pole breaks have occurred over the last five years and seven breaks have seriously injured people. Among these seven poles there was only one creosote-treated pole while there were three salt-treated and three untreated. It should be pointed out that the latter two categories constitute only 15 % of the total number of poles in Sydkraft's grids. Why do decayed salt-treated poles cause so many accidents? The main reason is lack of knowledge of soft rot and how to inspect a soft rot attacked pole. The site of decay below ground level has certainly not stimulated a thorough inspection of the pole even if the instructions have indicated this.

A feature of salt-treated poles which was noted at the strength tests is that the pole often breaks without any warning creaky sound and often after a relatively small deflection. An operator on the pole has no chance to take protective measures until the fall is a fact. The creosote-treated pole, on the other hand, gives a series of warnings before it falls to the ground and the operator has a better chance to avoid an accident.

Severe safety regulations are necessary, particularly if one considers that many of the salt-treated poles will be about 45 years old before they will be replaced.

REMEDIAL TREATMENT OF SALT-TREATED POLES

In 1959 Sydkraft carried out the first remedial treatment according to the Cobra method on 12-year old BIS-poles. In 1960-65 approx. 5,000 poles were reimpregnated; 1965-69 a few hundred only. In 1970 when systematic inspections on mainly salt-treated poles started, decay was found to an unexpected extent. This raised the consideration of remedial treatment as a deterrent to decay and a chance to postpone replacement 10 years. It was decided to reimpregnate all salt-treated poles having sufficient strength and in 1970-72 approximately 20,000 salt-treated poles were given supplemental treatment. The strength tests and the more efficient inspection methods showed that the poles were far more decayed than had been expected and the value of remedial treatment was reconsidered. A special inspection, completed with a microscopic examination by T Nilsson (Royal College of Forestry), of approx. 200 poles, of which every second was reimpregnated in 1962 and every second was left as control showed that the supplemental treatment was of some value but less than expected. The figure below shows the mean SR attack in re-impregnated poles and controls.



The mean failure load of reimpregnated poles was reduced to 63 % of a sound pole and to 55 % for the controls. It is supposed that a treatment at the correct time extends the service life by a maximum of five years instead of the earlier stated minimum of 10 years. However, the result also depends on the composition of the preservative. It is certainly possible to extend the service life by 10 years if the best preservative mixture is used. Generally, the opinion is that a remedial treatment of salt-treated poles must be carried out when there is slight decay only.

GUIDELINES FOR INSPECTION AND REPLACEMENT OF SALT-TREATED POLES

Background

All the inspections of salt-treated poles until the end of 1972 were carried out without any knowledge of soft rot attacked wood under the outer layer of the poles. Until then, a diameter reduction of 40 mm was taken as guideline for replacement. The number of replaced poles at this time was as low as 2-3 %. After the first strength tests in 1972 the permissible diameter reduction was changed to 20 mm for poles with a maximum ground line diameter of 270 mm and to 30 mm for poles with a ground line diameter greater than 270 mm.

Recent and more efficient inspection methods gave a drastically increased number of removed poles, on the average 40-50 % for cultivated land and woodland. Quite soon it was realized that measuring only the diameter was not satisfactory. Consideration must be given to the remaining sound diameter and the minimum permissible sound diameter thus determined. It was stated that low voltage lines should have at least 170 mm sound diameter and high voltage lines, 6-10 kV, 190 mm. These guidelines gave an average number of replaced poles of 30 % on cultivated land and woodland.

It should be emphasized that the guidelines for inspections presented below must not be considered as definite; they may be revised if future experiences demand so.

Planning the inspections

The distribution grids will be inspected for the first time 20 years after installation.

The inspection should be scheduled at intervals of 8 years. This means that different lines will be divided into eight groups of equal size. 1/8 will be inspected every year. Distribution lines with many salt-treated poles should have priority and should be inspected as early as possible.

Older grids generally consist of diverse materials concerning age and preservative treatment, particularly low voltage lines where rebuilding and new installations are frequent. It is often impossible to find out where different poles are located in order to carry out a selected inspection. Therefore, all poles - independent of preservative treatment and age - in a grid or line must be inspected the same year.

The inspector must be able to inspect the pole properly as well as to consider if its service life will last until next inspection in eight years. He must also be able to judge whether a condemned pole should be replaced immediately or at a planned replacement in two years. The inspector must be very reliable for safety and economic reasons. He must be well trained and have extensive experience.

General notes about pole dimension and replacement

The required dimension of a pole is determined according to Swedish Standard SEN 3601, height of the cable above ground, dimension of the cable and span width. All these factors must be considered for each pole if a strictly correct estimation is to be made. This is of course not practical for inspectors in the field who must instead be given simplified guidelines.

Emanating from normal spans in low and high voltage lines, cable areas have been divided into two and three groups respectively, having a fixed required sound diameter for different pole lengths. An attempt has thus been made to account for reduction in strength due to soft rot over the eight years preceding the next inspection. These guidelines are presented in appendix 6. If there are unusually large cable dimensions or extra high voltage lines, the inspector must be given information about minimum diameter for different pole lengths in each case.

Inspection records

During inspection a record is set up in which the poles are registered independent of preservative treatment and age. For salt-treated poles the original and remaining diameters are recorded as is the urgency for replacement, i.e. immediately or within two years. One reason for noting the remaining sound diameter is the present inadequate knowledge of the rate of the decay. In this way it is possible to take samples four or five years after the inspection and then, if necessary, carry out the next inspection earlier than originally planned. A proposal to an inspection record is shown in appendix 5. The purpose of this work has, of course, been to create an acceptable scheme for inspections of salt-treated poles and a proposal is presented in appendix 6.

SUMMARY

Within those areas of southern Sweden, where Sydsvenska Kraftaktiebolaget is responsible for the distridution of electricity, creosote-treated poles dominate. During the second world war when no creosote was available the poles were impregnated with various combinations of salt preservatives, mainly Boliden BIS-salt. In the grids of Sydsvenska Kraftaktiebolaget there presently are about 700,000 poles of which about 600,000 were treated with creosote and about 100,000 were treated with salt preservatives during the 1940s.

In this paper experiences from inspections and strength tests of soft rot attacked poles are described. A summary of the most significant points is presented as follows.

1. The cost for replacing a pole is so high that persons specially trained for rot inspection are required. They must be able to judge the pole correctly so it will be replaced at the right time, according to personnel safety, operational safety and optimal economy.
2. The strength tests have shown that the extent of soft rot attacks are decisive for the life of a salt-treated pole. The tests have also given new ideas for inspection methods.
3. The most serious soft rot attacks occur below ground level, the better the surrounding stone filling, the lower the level.

Consequently, a salt-treated pole must be uncovered to a certain depth in order to detect the damage.

4. Soft rot attacks always begin on the surface of the pole and extend inwards.
5. Poles in cultivated soil show a considerably higher degree of soft rot attack than poles in other types of soil. The percentage of rejected poles is approximately four times higher in cultivated soil.
6. Sufficient experience of the rate of progress of a soft rot attack in a pole is not yet available.
7. The so-called "orange rot" has shown a trend to increase as the poles get older.
8. When determining the pole dimensions for construction of new lines, one should increase the normally specified ground level diameter to allow a certain degree of soft rot.
9. Regarding the safety of personnel, specific instructions must be made.
10. An evaluation of reimpregnation by the Cobra-method has been made.
11. The paper shows how the instructions for rejecting salt-treated poles attacked by soft rot have gradually changed. An orientation on pole inspections and instructions for soft rot inspections are also described.

ACKNOWLEDGEMENTS

We are indebted to Björn Henningsson and Thomas Nilsson, the Royal College of Forestry, Preben Hoffmeyer, the Technical University of Denmark and Henning Friis-Hansen, Svenska Reimpregnerings AB Cobra, for valuable discussions and cooperation.

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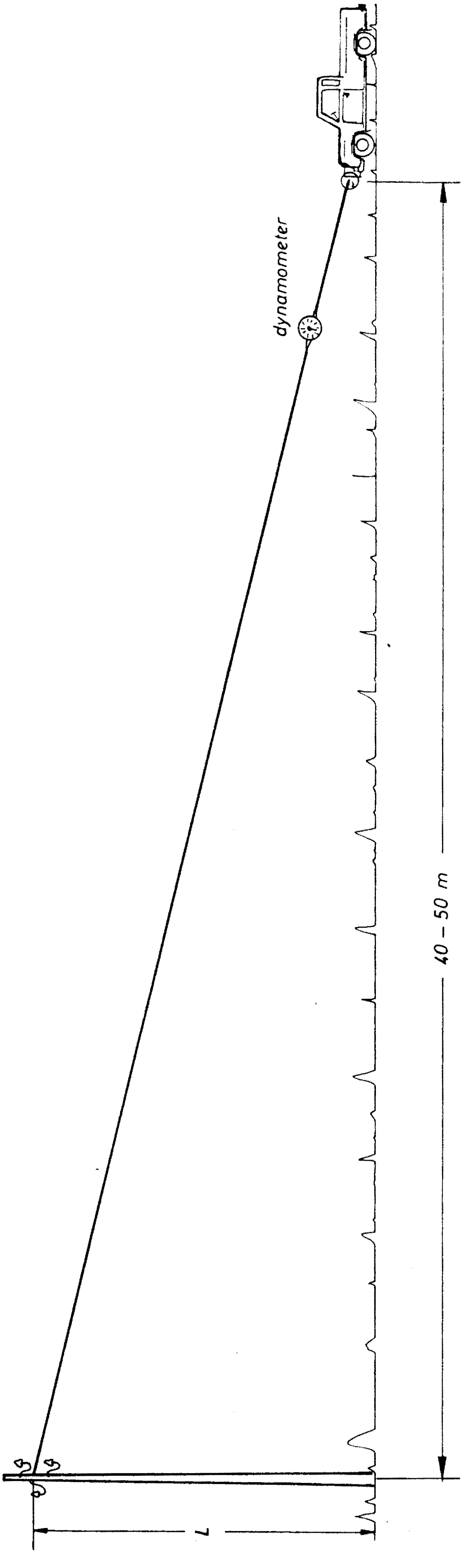
Appendix 1



STRENGTH TEST RECORD

Appendix 2

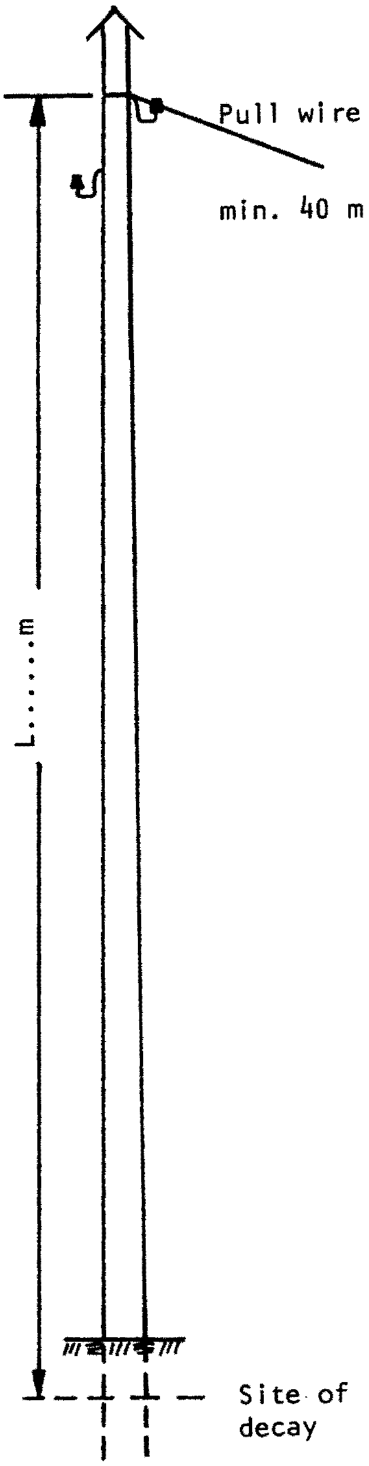
Sheet no...

Strength test of salt-treated poles. Date...........

Line......................Grid....................

Pole no.........Preservative..............Year....

Wires........................Span length.........m



Inspection

1. Site of decay ± ground level...................cm
2. Pole diameter, greatest decay..................mm
3. Poking no. 1.........mm, compass location..........

   Poking no. 2.........mm, compass location..........
4. Boring no. 1: SR4....mm SR3-2....mm

   compass location..........

   Boring no. 2: SR4....mm SR3-2....mm

   compass location..........
5. Width of annual rings.......mm
6. Pull direction (compass)......

Calculations for bending

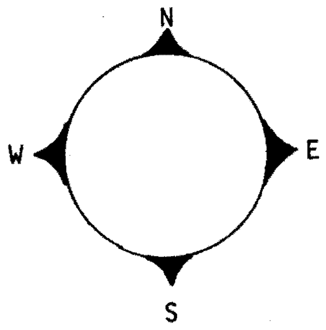
$\sigma_{permissible} = 2.1\ kN/cm^2$ $\sigma_{rupture} = 5.0\ kN/cm^2$

1. Calc. failure load, sound pole.................kN
2. Calc. failure load, poking.....................kN

   Remaining Ø...............mm
3. Calc. failure load, boring no. 1 and 2

   SR4....... + ...mm SR3-2....... + ...mm

   Calculated failure load........................kN
4. Calculated failure load, instrument............kN
5. Load by wind on ice-covered wires, insulators and pole-top..................kN
6. Actual failure load........kN
7. Remarks



RECORD OF STRENGTH TESTS OF SALT-TREATED TRANSMISSION POLES 1972-1974

Sheet no 1

Date	Data							Method of inspection						Judgement of damage for calculation of failure load										Calculated failure load kN							Actual failure load		Remarks
															Ø reduction mm			Degree of soft rot, mm by judgement of borings										Borings					
																		Visual inspection		Microscopic inspection													
	Test series	Line / Grid	Pole no	Impregnated, year	Reimpregnated, year	Type of land	Ø ground level	Knocking	Boring	Axing	Poking	Instrument	Microscope	Site of decay ground level ± cm	Axing	Poking	Instrument	4	3-2	4	3	2	1	Sound pole	Regulated minimum	Axing	Poking	Visual inspection	Microscopic inspection	Instrument	kN	% of calculated value for sound pole	
19.6.72		Berga 10 kV	3782	41		Field	250	X		X				- 30	40									10.4	3.4	6.2					1.9	18	
25.10.72		Kälsved Low voltage	1884	41	64	Forest	210	X		X				-10	20									6.0	3.4	4.4					2.3	38	
"		"	1885	41	64		240	X		X				-10	30									7.8	3.4	5.9					2.4	31	
"		"	1886	41	64	"	220	X		X				-10	20									6.9	3.0	5.2					2.0	29	
"		"	1887	41	64	"	220	X		X				-10	15									6.7	2.8	5.4					2.5	37	
"		"	1889	41	64	"	200	X		X				-10	20									5.2	3.0	3.8					1.8	35	
"		Älmhult 10 kV	574	44	—	"	225	X		X				—	0									6.4	3.3	6.4					5.5	86	Repture 0.6 m above ground level
"		"	575	44	—	"	285	X		X				—	0									12.0	3.2	12.0					9.0	75	Split fracture, 2 m crack
"		"	576	44	—	"	285	X		X				-20	20									9.5	3.4	7.7					6.2	65	
"		"	584	44	—	"	225	X		X				—	0									6.0	3.2	6.0					3.8	63	Also attacked by white rot
"	A	"	586	44	—	"	210	X		X				-10	40									5.2	3.1	2.8					3.5	67	
"		"	596	44	—	"	190	X		X				-10	35									4.2	3.2	2.0					2.8	67	
"		"	597	44	—	Pasture	240	X		X				-10	35									8.1	3.1	5.0					2.5	31	
"		Svanaboda, Low voltage	3332	46	—	Forest	220	X		X				-10	15									6.5	2.7	5.2					4.1	63	
"		"	3333	46	—	Field	230	X		X				-10	10									8.7	2.6	7.6					6.0	69	Split fracture, 4 m crack
"		Brokhult, Low voltage	7618	46	—	Forest	210	X		X				-10	10									6.6	3.7	5.7					5.3	80	
"		"	7619	46	—	"	210	X		X				-10	15									5.6	4.2	4.5					2.8	49	
"		"	7620	46	—	Field	220	X		X				-20	20									6.8	4.2	5.1					3.2	47	
"		"	7621	46	—	"	210	X		X				-20	20									6.5	4.2	4.1					3.6	55	160 mm heartwood diameter
"		"	7623	45	—	"	210	X		X				-10	20									7.0	3.0	5.2					3.5	50	150 mm heartwood diameter
"		"	7624	45	—	"	250	X		X				- 20	10									10.0	3.0	8.8					3.8	38	
"		"	7625	46	—	"	240	X		X				-10	20									8.6	3.3	6.6					5.5	64	
"		"	7742	46	—	"	240	X		X				± 0	30									7.6	5.1	5.8					3.8	50	170 mm heartwood diameter
"		"	7744	46	—	Pasture	190	X		X				-20	20									4.6	3.7	3.0					2.5	54	
"		"	7745	46	—	"	210	X		X				-10	20									5.7	3.7	3.6					3.0	53	

RECORD OF STRENGTH TESTS OF SALT-TREATED TRANSMISSION POLES 1972-1974

Sheet no 2

Date	Data							Method of inspection						Judgement of damage for calculation of failure load										Calculated failure load kN							Actual failure load		Remarks
	Test series	Line / Grid	Pole no.	Impregnated, year	Reimpregnated, year	Type of land	Ø ground level	Knocking	Boring	Axing	Poking	Instrument	Microscope	Site of decay ground level ± cm	Ø reduction mm			Degree of soft rot, mm by judgement of borings						Sound pole	Regulated minimum	Axing	Poking	Borings		Instrument	kN	% of calculated value for sound pole	
															Axing	Poking	Instrument	Visual inspection		Microscopic inspection								Visual inspection	Microscopic inspection				
																		4	3-2	4	3	2	1										
25.10.72	A	Hallaryd 10 kV	889	46	71	Bog	220	X		X				± 0	10									7.2	2.9	5.4					2.8	39	
"		"	891	46	71	Forest	240	X		X				-20	10									7.4	2.9	6.9					4.3	57	
19.12.72		Kalsved Low voltage	1853	41	64	Field	220	X	X	X				-10	20			60						7.1	2.9	5.3		2.7			1.8	25	Also attacked by white rot
"		"	1854	41	64	"	210	X	X	X				-10	50			70						6.1	2.9	2.7		1.8			1.3	21	
"		"	1860	48	64	"	190	X	X	X				-10	10			10						4.6	2.9	3.9		3.9			3.1	67	
"		"	1822	41	64	"	200	X	X	X				-10	20			40						5.8	2.4	4.2		3.0			2.3	39	
"		Osbyorten 6 kV	652	42	64	"	250	X	X	X				-10	10			10						8.7	3.0	7.7		7.7			5.5	63	Rupture 4 m above ground level
"	B	"	656	42	64	"	250	X	X	X				-10	10			20						9.2	2.5	8.1		7.1			2.8	30	
"		"	657	41	64	"	280	X	X	X				-10	10			70						12.5	3.4	11.2		5.3			4.6	37	
"		"	658	41	64	Forest	270	X	X	X				-10	10			10						9.8	3.5	8.8		8.8			7.0	71	Split fracture, 2 m crack
"		"	659	41	64	"	260	X	X	X				-10	10			20						10.0	3.4	8.9		7.9			6.5	65	Split fracture, 2 m crack
"		"	660	41	64	"	260	X	X	X				-10	5			40						10.3	3.3	9.8		6.3			5.1	49	SR in 1/3 of the circumference
"		"	661	41	64	"	250	X	X	X				-10	10			30						9.0	3.4	8.0		7.5			5.8	64	
"		"	662	43	64	"	240	X	X	X				-10	0			0						8.1	2.5	8.1		8.1			6.3	77	
21.8.73		50 kV Ava-Vxo	23-1	45	71	Field	330	X	X		X		X	-40		50		25	20	10	10	20	10	13.0	8.0		8.0	6.4	5.5		6.8	52	
"		"	23-2	45	71	"	350	X	X		X		X	-40		40		35	20		5	5	40	15.6	8.0		10.7	6.4	10.2		9.0	58	
"		"	27-1	45	71	"	300	X	X		X		X	-40		40		55	10		10	10	40	12.0	7.7		7.8	2.6	6.2		5.5	46	
"	C	"	27-2	45	71	"	340	X	X		X		X	-40		50		30	20	30	20			17.4	7.7		10.5	7.8	5.9		6.0	34	
"		"	53-1	45	71	"	360	X	X		X		X	-40		50		25	40	10	10	45		17.4	8.0		11.0	7.3	5.9		6.0	46	
"		"	53-2	45	71	"	360	X	X		X		X	-40		50		55	30	10			30	17.0	8.0		10.3	8.0	8.2		6.0	35	

RECORD OF STRENGTH TESTS OF SALT-TREATED TRANSMISSION POLES 1972-1974

Sheet no .. 3 ..

Date	Data							Method of inspection						Judgement of damage for calculation of failure load										Calculated failure load kN							Actual failure load		Remarks
	Test series	Line / Grid	Pole no.	Impregnated, year	Reimpregnated, year	Type of land	Ø ground level	Knocking	Boring	Axing	Poking	Instrument	Microscope	Site of decay ground level ± cm	Ø reduction mm			Degree of soft rot, mm by judgement of borings						Sound pole	Regulated minimum	Axing	Poking	Borings		Instrument	kN	% of calculated value for sound pole	
															Axing	Poking	Instrument	Visual inspection		Microscopic inspection								Visual inspection	Microscopic inspection				
																		4	3-2	4	3	2	1										
27.9.73		Sövestad 1269 Low voltage	1905	41	70	Field	225	X	X		X			-20		52		20	30					9.0	4.0		4.4	3.1			1.8	20	
"		"	1904	41	70	"	215	X	X		X			-20		72		25						7.5	4.1		2.2	3.4			3.0	40	
"		"	1903	41	70	"	215	X	X		X			-20		90		50						7.5	4.1		1.5	1.1			1.7	23	
"		"	1902	41	70	"	220	X	X		X			-20		35		25	15					8.1	4.1		4.8	2.8			2.6	32	
"		"	1901	41	70	"	220	X	X		X			-20		90		45						8.1	4.1		1.7	1.7			1.5	19	
"		Sövestad 1238 Low voltage	1522	41	70	"	210	X	X		X			-20		62		35						6.7	3.2		2.4	2.0			2.1	31	
"		"	1521	41	70	"	235	X	X		X			-20		65		30	20					8.2	3.3		3.2	2.3			3.6	44	
"		Sövestad 1333 Low voltage	1326	41	70	"	240	X	X		X			-20		62		50						7.7	3.8		3.2	1.5			2.2	.29	
"	C	Sövestad 6 kV	1237	41	70	"	230	X	X		X			-20		93		60						7.3	3.6		1.6	0.8			1.3	18	
"		"	1234	41	70	"	250	X	X		X			-20		86		40	20					9.7	3.5		2.7	2.1			1.8	19	
"		Sövestad 1238 Low voltage	1506	41	70	"	210	X	X		X			-20		90		50						6.8	3.2		1.3	1.0			2.4	35	Very tough heartwood
"		Onslunda 6 kV	2103	44	70	"	250	X	X		X			-20		50		25	15					9.2	4.2		4.7	3.2			2.2	24	
"		"	2110	44	70	"	220	X	X		X			-30		60		30	10					6.3	4.2		2.4	2.0			1.6	26	
"		"	2112	44	70	"	250	X	X		X			-20		40		20	20					10.7	4.1		6.4	4.7			3.0	28	
"		"	2118	44	70	"	240	X	X		X			-20		40		20	15					7.8	4.1		4.5	3.0	3.0		3.0	39	
"		"	2120	44	70	Pasture	210	X	X		X			-20		25		15	15					6.3	4.3		4.3	3.1	5.1		3.5	56	
6.11.73		50 kV Dhn-Ghn	570-1	42	64	Pasture	230	X	X		X	X	X	-20		65	39	10	60		10	20	10	6.4	5.3		2.2	2.9	2.8	3.8	2.0	31	
"		"	570-2	42	64	"	220	X	X		X	X	X	-10		120	75	10	60	10	10	30	10	5.8	5.3		0.5	2.4	1.8	1.9	1.5	26	
"		"	576-1	42	64	"	250	X	X		X	X	X	-10		67	45	8	30	10		10	10	6.6	5.3		2.6	4.3	3.8	3.7	4.5	68	
"		"	576-2	42	64	"	270	X	X		X	X	X	-10		47	56	8	30	10			20	8.3	5.3		4.7	5.5	3.3	4.3	4.4	53	
"	D	"	618-1	42	64	Scrub land	245	X	X		X	X	X	-10		15	22	5	50			10	10	8.1	4.0		6.7	4.9	5.3	6.3	5.4	67	Repture 1.2 m above ground level at a large knot
"		"	618-2	42	64	"	195	X	X		X	X	X	-10		20	22	5	30	10		10	20	4.1	4.0		2.9	2.9	1.9	2.9	2.8	67	Repture 0.4 m above ground level
"		"	623-1	42	64	"	205	X	X		X	X	X	-10		18	15		60	10			20	4.8	4.0		3.7	2.7	2.8	4.1	3.7	77	
"		"	623-2	42	64	"	220	X	X		X	X	X	-10		4	8	5	80			20	10	6.0	4.0		5.6	2.9	3.7	5.4	4.7	78	

RECORD OF STRENGTH TESTS OF SALT-TREATED TRANSMISSION POLES 1972-1974

Sheet no 4

Date	Data							Method of inspection						Judgement of damage for calculation of failure load										Calculated failure load kN							Actual failure load		Remarks
	Test series	Line / Grid	Pole no.	Impregnated, year	Reimpregnated, year	Type of land	Ø ground level	Knocking	Boring	Axing	Poking	Instrument	Microscope	Site of decay ground level ± cm	Ø reduction mm			Degree of soft rot, mm by judgement of borings						Sound pole	Regulated minimum	Axing	Poking	Borings		Instrument	kN	% of calculated value for sound pole	
															Axing	Poking	Instrument	Visual inspection		Microscopic inspection								Visual inspection	Microscopic inspection				
																		4	3-2	4	3	2	1										
6.11.73		50 kV Dhn - Ghn	625-1	44	64	Scrub land	230	X	X		X	X	X	- 10		4	13	5	60		5	15	10	6.7	4.0		6.4	3.7	3.3	5.8	4.2	63	
"		"	625-2	44	64	"	225	X	X		X	X	X	- 10		70	36	5	50			40	10	6.3	4.0		2.1	3.1	3.7	3.8	2.4	38	
"		"	656-1	44	64	"	245	X	X		X	X	X	- 10		35	11		60			10		8.2	4.0		5.2	5.1	3.8	7.3	5.0	61	
"		"	656-2	44	64	"	265	X	X		X	X	X	- 10		29	9	5	30		10	10	10	10.2	4.0		7.1	8.8	5.1	9.4	7.1	70	
"		"	662-1	44	64	Field	235	X	X		X	X	X	-10		58	28	8	40	10	10	20		7.3	4.0		3.1	4.1	2.6	5.0	4.7	65	
"		"	662-2	44	64	"	225	X	X		X	X	X	-10		112	83	5	70	10	10	20	10	7.3	4.0		0.8	2.6	2.1	1.6	1.7	23	
"		"	665-1	44	64	"	235	X	X		X	X	X	-10		65	48	8	50	10	10	10	10	7.3	4.0		2.8	3.7	2.7	3.8	3.1	43	
"		"	665-2	44	64	"	240	X	X		X	X	X	-10		85	52	10	50		30	30	10	7.8	4.0		2.1	3.7	3.1	3.8	2.7	35	
19.4.74	D	50 kV Kbg - Sla	18-1	46	–	"	240	X	X		X	X	X	-15		34	35	10		5	5	20	5	6.9	3.6		4.4	5.4	3.3	4.4	2.9	42	Rupture 0.6 m above ground level
"		"	18-2	42	–	"	285	X	X		X	X	X	-15		59	48	15		10	20			11.6	3.6		5.8	8.5	5.9	7.3	5.1	44	
"		"	23-1	42	–	"	285	X	X		X	X	X	-15		80	60	20	10	10	20	10	10	10.1	3.7		4.2	6.2	4.0	5.5	4.6	41	
"		"	25-1	–	–	"	230	X	X		X	X	X	-10		48	55	10			10	10	10	7.2	3.5		3.5	4.8	2.6	3.2	1.7	24	
"		"	45-1	–	–	"	225	X	X		X	X	X	-20		77	60	10	37	10		30		6.9	3.5		2.0	2.9	3.0	2.8	1.5	22	Rupture 0.3 m above ground level
"		"	S-1	46	–	"	230	X	X		X	X	X	-15		70	70	25		10	20	10	10	7.8	1.5		2.8	3.8	2.6	2.8	1.8	22	
"		"	S-2	46	–	"	200	X	X		X	X	X	-15		60	53	12	15	10	10	20	10	5.7	1.5		2.0	2.9	1.9	2.3	1.6	28	
"		"	S-3	46	–	"	240	X	X		X	X	X	-20		52	60	15	25	10	10	20		9.1	1.5		4.4	4.3	3.3	3.9	3.8	41	
"		"	S-4	46	–	"	220	X	X		X	X	X	-10		83	56	24		5	25	10	10	7.1	1.5		1.7	3.5	2.4	3.0	1.8	25	
"		"	68-2	46	–	"	270	X	X		X	X	X	-10		22	38	6	10	5	20	10		10.0	3.7		7.8	7.6	3.5	6.3	3.9	39	
"		"	81-2	46	–	"	230	X	X		X	X	X	-10		16	20	3				20	10	7.8	3.5		6.0	6.8	4.6	5.7	3.4	44	
"		"	83-2	45	–	"	215	X	X		X	X	X	- 5		69	67	12		10	10	10	10	6.5	3.5		2.0	4.4	1.8	2.1	1.0	16	80 mm heartwood diameter

Fig 1.

Salt-treated pole from 1941. Strength tested in 1972. Calculated bending strength of sound pole: 6.8 kN. Residual strength at test: 2.4 kN. Note the typical soft rot fracture in the sapwood.

Fig 2.

Creosote-treated pole from 1938. Strength tested in 1974. Calculated bending strength for sound pole: 7.6 kN. Residual strength at test: 4.2 kN. Note the complicated and tough fracture, typical of creosoted poles.

Fig 3.

Salt-treated pole from 1942 with heavy attack of "orange-decay". This pole was not strength tested. Note the characteristic "orange-decayed" sapwood under the outer crust.

SYDKRAFT

DECAY INSPECTION RECORD

Line .... kV .... — ....

Grid ....

High voltage ☐

Low voltage ☐

Inspector ....

Date ....

Sheet ....

Pole no.	Year marker	Creosoted pole		Salt-treated pole	Pole length m	Overhead line area mm			Overhead cable			Ground level diameter mm	Creosoted pole sound crust mm		Salt-treated pole diameter mm		Replacement						Other damages						Remarks
		< 25 years	≥ 25 years			10 - 35	49 - 99	157 - 234	One	Two	Three		Least	Diametrically	Reduction	Remaining sound	Immediately	Within 2 years	Reason				Lean	Stay	Insulator	Conductor	Protective guard	Clearing	
																			Decay			Other							
																			Ground level	Middle	Upper								

Appendix 6

INSPECTION SCHEME

Excavating poles

Poles on cultivated land are excavated at their bases to a depth of 15-20 cm below the ground level. Poles with ordinary backfill material on all other types of land are uncovered to a depth of 25-30 cm below the ground level. If the surrounding ground level has been displaced upwards for different reasons, the pole must be uncovered to the original level before the real excavation is done. If the displacement is more than 80 cm, it must be excavated to this depth.

If the inspector does not find the above mentioned depths adequate, the depth must be increased so a proper inspection can be performed. Given a completely open backfill of rock without any soil close to the pole, the backfill must be taken away whereupon the pole is exposed to a depth of 15-20 cm. A backfill deeper than 80 cm is just taken away and no further uncovering is necessary.

Inspection

At the ground level the pole is inspected in this way:

1. To find out where the pole is decayed it is examined with an axe to approximately 50 cm above the ground level.

2. Where the most serious decay is observed, a boring is taken and visually inspected. The depth of soft, totally decayed wood is registered as well as the depth where a greyish discolouration is observed. This is far more pronounced for damp wood than for dry which makes the visual inspection of incompletely decayed wood somewhat hazardous as the moisture content can vary considerably from pole to pole.

3. Close to where the boring is taken, poking is done with an awl. Pieces of wood are broken loose and the surface of fracture is observed. The surface is dark and abrupt in strongly soft rot attacked wood. The abrupt fractures and the discolouration decrease as the soft rot attack decreases.

The poking must advance inwards until the fibres are found to be tenacious and a cracking sound can be heard when they break. To be able to judge correctly, the hole must be wide enough that pieces big enough can be broken out. One difficulty is to determine when the poking should cease. This is of importance, however, only in cases where it is uncertain if the pole must be replaced or not. The method is also influenced by the moisture content in the wood; a dry pole is more difficult to judge than a wet one. The wood seems to be better than it really is. After the poking, the depth of the hole is measured and registered. A similar poking is performed on the opposite side of the pole where it is most decayed. The hole is made within ± 45° from a point diametrically opposite to the first hole.

4. The visual inspection of the borings is compared with the depths from the poking, and the remaining sound diameter is determined. Original diameter as measured by calipers at the worst damage and remaining sound diameter are recorded. If the boring and poking differ too much, the pole is re-assessed.

5. The inspector estimates whether the pole must be replaced. Poles remaining until next inspection must have a minimum sound diameter according to the following table.

Minimum permissible diameter.

Line area mm^2	Low voltage pole diameter mm				High voltage pole 3-20 kV diameter mm					
					Without ground connection			With ground connection		
	8 m	9 m	10 m	11 m	11 m	12 m	13 m	11 m	12 m	13 m
10-35	-	170	180	190	190	200	210	200	210	220
49-99	-	180	190	200	200	210	220	210	220	230
157-234	-	-	-	-	210	220	230	220	230	240
Overhead cable										
one	150	160	170	-						
two	170	180	190	-						
three	190	200	210	-						

Remarks: 1. Given figures must be increased by 10 mm where the line crosses roads or other public areas.

2. Given figures are reduced by 20 mm for 1-phase low voltage overhead lines.

3. Overhead cable = overhead cable with free or encased strands.

For a pole which is going to be replaced the inspector has to judge if it must be replaced directly or within two years at planned replacement. The greatest importance in this case is given to the consideration of personnel safety. Under normal weather conditions, if an unloaded pole is dangerous to climb, it must be replaced at once. A pole must be replaced immediately if the remaining sound diameter is below 140 mm for high voltage lines and 120 mm for low voltage lines.

Such a pole should be marked with two red plates, one on each side of the pole in the direction of the line. Climbing must not take place without previous bracing. Poles judged fit for another two years, however, are marked with a white plate.

6. That part of the pole above the ground level which can be reached by the inspector is examined by axe and eventually, by taking borings. The upper and middle sections of the pole are normally inspected visually. All sighted weakness, such as that caused by lightning, woodpeckers and serious cracks resulting from frost injuries for example, are observed.

If the inspection is impossible to do from the ground and climbing the pole is necessary, this should be noted in the record and the inspection carried out later. Poles judged to merit replacing because of damage in the middle or upper sections are marked as mentioned above. If damage occurs at ground level or in the middle or upper sections, although not serious enough in themselves to necessitate replacement of the pole, an over-all judgement might give rise to a replacement.