EXPERIMENTAL AND NUMERICAL STUDIES OF THE REELSPOOL AND THE PARENT ROLL INTERACTION UNDER GRAVITY FORCES

by

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ABSTRACT

In wide paper machines, gravity forces may cause excessive stresses to the paperlayers of the parent roll due to bending of the reel spool. Experimental and numerical studies of these effects will be described in this paper. Experiments done by strain gage measurements and numerical techniques involved will be described in the first part of the paper. In the second part, the same phenomena are studied by using FE modelling.

First, measurement techniques of reel spool bending strains is described. Measurements are done in static loading situations using several differently reeled parent rolls. Then, a method to estimate the contact pressure distribution between the parent roll and the reel spool from the measured bending strains is presented. Calculated experimental results are compared qualitatively and quantitatively to the FE modelling of the same situation. The unknown elastic orthotropic coefficients of the parent paper roll are estimated so that the finite element calculations give practically the same results as the experiments. Finally, FE model is used for further numerical studies of different reeling recipes etc.

The most essential result of the measurements and numerical studies is that the reel spool carries the parent paper roll almost entirely at the edges of the spool causing large stresses to the paper layers in this area. The well known fact is that most printing roll defects are found from roll sets, which are made from edge and inside part of the parent roll.

Research results have changed the design philosophy of the reel spool for various paper grades, as machines are made for heavier and heavier reels. Experimental work is much more laborious and time-consuming than numerical studies, and therefore even a bit vaguely calibrated FE model is very effective design tool for new concepts.

NOMENCLATURE

A	bearing reaction force of parent roll
a_0, a_1, a_2	coefficients of the fourth order polynom
b	reel spool shell length
D	reel spool shell diameter
d	diameter of the parent roll
E_1	elastic modulus in radial direction
E_2	elastic modulus in tangential direction
E_3	elastic modulus in cross machine direction
G_{12}, G_{13}, G_{23}	orthotropic shear moduli
L	web width
l_0	half of web width
l_1	half of bearing distance
M_0, M_1, M_2, M_3	bending moments
P	radial stress of the paper roll
p	pressure against reel spool
p_0, p_1	parameters of pressure distribution
ν_{12}, ν_{13}, ν_{23}	Poisson's ratios
ϕ	angle from vertical
μ	friction coefficient between paper and reel spool
ρ	density of paper

INTRODUCTION

The reeling process in paper mills is a compact way to store paper temporarily in the form of large rolls. Demands set for reeling have become more and more challenging due to increasing machine speeds, higher productivity needs and new on-line coating and calendering concepts. In early 1990´s, all major paper machine manufacturers introduced new reeling technology in the form of "second generation reels" to the market. These reels can handle parent rolls 3 to 5 times heavier than before with diameters up to four meters and speeds going up to 2000 m/min, and still reel waste and web breaks are only one fourth of the machines of the late 1960's. This fast development has also changed the design principles of the reel spools. In a modern 10 m wide paper machine, the reel spool weight may be 20 tons and the diameter of the spool can be 1.3 m. An example of a modern second-generation reel is shown in Figure 1.

When developing new second-generation reels one essential step has been to investigate the reel spool and the parent roll interaction in the reeling process. To understand better what happens in the reeling process, both experimental and theoretical research has been done in various places. Many phenomena, which now are self-evident, were not self-evident at all ten years ago.

EXPERIMENTAL STUDIES

Background

Traditionally reel spools have been sized based upon shell or journal stresses, or critical speed, and not on the reeling process itself. One assumption of dimensioning reel spools has been that the parent roll weight forms an evenly distributed load to the reel spool shell. At Valmet Corporation (now Metso Paper, Inc.), this assumption was experimentally examined in a paper machine of 7.5 m web width in 1969. The measurement results confirmed that the assumption was correct. However, according to our knowledge now, there must have been some error in the measurements.

When developing the first version of a new second generation reel, the parent roll - reel spool interaction was experimentally studied again, and the studies resulted in new findings, which also have been verified by FE-calculations and by research made at other companies and research institutes. Those experimental and numerical studies are the subject of this paper.

Objects

The object of the study is to find out explanations to reeling defects by studying how the gravity loading of the parent roll paper is distributed in cross machine direction. Second object is to examine what effect differently reeled parent roll has on the reel spool bending and interaction phenomena i.e. to find out if it is possible to control excess stresses by choosing right reeling recipes. This principle is presented in Figure 2.

Strain gage instrumentation. A reel spool (bearing distance of 8.55 m, shell diameter of 0.725 m and shell length of 7.85 m) is instrumented with strain gages at four sections of the shell (Figure 3) on the opposite sides of each section. Strain gages are connected in a half bridge circuit to measure bending strain of the reel spool shell in each section. Strain gages are installed before covering the shell with thin polyurethane layer.

Load resultant. When the parent roll is reeled a pressure distribution is formed between the reel spool and the paper roll. Resultant linear load distribution can be calculated. When cross machine linear load distribution is known, the equations for bending moment distribution are formed using classical beam theory. From the measured bending strains it is possible to calculate bending moments in each measured section when the dimensions of the reel spool are known. Principle of the method and coordinate system used is clarified in Fig. 4.

By subtracting bending strains from the measured total strains caused by reel spool own weight bending moments caused by the paper roll can be calculated. Using these ideas and remembering that the weight of the parent roll is also known following equations are formed for solving the unknown load resultant at each measured section.

The support reaction of the weight of paper is then

$$A = \int_0^{l_0} q(x)dx \; . \qquad \{1\}$$

The bending moment caused by the loading of the reel paper at point x is

$$M = A(l_1 - x) - \int_x^{l_0} q(u)(u - x)du \; . \qquad \{2\}$$

The unknown linear load distribution is assumed to be symmetrical fourth order polynom with reference to the center of reel

$$q(x) = a_0 + a_1 x^2 + a_2 x^4 . \qquad \{3\}$$

Substituting {3} to the equation {1} and {2} four (five) linear equations are obtained for solving unknown coefficients a_0, a_1 and a_2. The measurement results from section 3 at the end part of the reel spool are not used in the calculations, because the reel spool structure in that area is more complicated and the assumption used do not hold any more.

The four equations are solved by using the standard weighted least-squares method weighing the support reaction A ten times as compared to the bending moments calculated from the measurements.

Estimation of the pressure distribution. A rough estimation of the pressure distribution in the surface of the reel spool is obtained by assuming a cosine law pressure as in Fig. 5.

$$p(x,\phi) = p_0(x) + p_1(x)\cos(\phi) \qquad \{4\}$$

By integrating the vertical component of the pressure over the reel spool surface {5} an equation between q (x) and pressure difference of the upper and lower surface is obtained, equations {6} and {7}.

$$q(x) = \int_0^{2\pi} p(x,\phi)\cos(\phi)\frac{D}{2}d\phi . \qquad \{5\}$$

$$p_1(x) = \frac{2q(x)}{\pi D} . \qquad \{6\}$$

$$\Delta p(x) = 2p_1(x) . \qquad \{7\}$$

Calibration. Using a point force (5500 – 8000 N) in the center of the reel spool and comparing the measured bending moments to theoretical values have been used to check the measurement system.

Results. Two samples of the measurement results, which are made by using the instrumented reel spool, are shown in Fig. 6 and Fig. 7. Paper grade examined is LWC base paper. Parent rolls are wound with Pope reel in "soft" (nipload 0.8 N/m) and "tight" (nipload 1.8 N/m) practice. There are distinct differences between found load distributions.

NUMERICAL CALCULATIONS

Goal of the study

The goal of the study is to develop a FE model to calculate the paper machine parent roll stresses. Also study internal stresses in a parent roll with different roll structures.

FE – model

The used FE model is as pictured in Fig.8. Reel spool and paper roll is modeled using 20 nodes brick elements. The model is ¼ of the real size and utilizes symmetry boundary conditions. Non-linear contact definition is made between the paper roll and reel spool. In the calculations, a penalty friction formulation, which can be applied to calculations of minor slide, is used. The rubber coating of reel spool is ignored.

The analysis is made with Abaqus 5.8 program.

Material constants

Paper grade is LWC base paper.

$\rho = 680$ kg/m^3
$E_1 = 13.8*P + 12*P^2$ N/mm^2
$E_2 = 6200$ N/mm^2
$E_3 = 1500$ N/mm^2
$\nu_{12} = \nu_{13} = 0.001$
$\nu_{23} = 0.15$
$G_{12} = G_{13} = 30$ N/mm^2
$G_{23} = 1300$ N/mm^2
$\mu = 0.4$
$L = 7.63$ m
$d = 2.5$ m
$D = 0.715$ m

Loads

The analysis consists of two phases:

In the first phase, the paper is pre-tensioned in order to receive a wanted paper roll structure. Using negative temperature makes the pre-tensioning. The roll structures to be studied are shown in Fig. 9. The radial elastic modulus is non-linear. This non-linearity is taken into account, when the pre-tensioning is carried out.

The second phase of the analysis consists of calculations for the stresses and displacements due to gravitation. The analysis is geometrically non-linear. In the second loading case, the radial elastic modulus of the paper is linear.

Stresses

The stress change, which is caused by the gravity to the paper roll, is studied in the calculations. Stress change is used, if needed, in defining the amount of stress amplitude, which the paper is exposed to during the parent reel rotation. If the total stresses are needed, they are gained by combining the stress of paper pre-tensioning (which is known) to the stress caused by the gravity.

The stresses in Fig. 10 – 12 are printed from the upper edge of the paper roll inside nip, from middle line of the parent reel to the end of the roll.

Radial stress

The calculated radial stresses are shown in Fig. 10. The figure shows that with a hard and constant pre-tensioned bottom, the paper roll support its load almost entirely on its ends. In the middle of the parent reel, the radial stress changes its sign, and the paper roll supports the reel spool. With a soft bottom, the support of the paper to the reel spool is very low. The value of the radial stresses in relation to the pre-tension is small, and the contact between paper roll and reel spool is maintained.

Tangential stress

The calculated tangential stresses are shown in Fig. 11. The tangential stress values are high in relation to the axial stresses, and the highest values are gained from the roll ends. If the paper thickness is assumed to be 0.06 mm, the tangential stress of 1 N/mm² corresponds to the web tension of approximately 17 N/m. With a soft bottom, the stress amplitude of 12 N/mm² corresponds to the web tension amplitude of 204 N/m in the roll.

Axial stress

The calculated axial stresses are shown in Fig 12. Axial stress values are low. The change of axial stress direction at the end of roll end with soft bottom roll is to be noted. With a soft bottom, the radial stress is low, and slide occurs between reel spool and paper roll.

CONCLUSIONS

We believe that both of the two research methods described in this paper: experimental and numerical modeling is still needed in future. Numerical modeling methods are developing fast, but the main problem found also in this paper still is how to find right values for material constants needed. A clever combination of experiments and theoretical computer methods are still needed to make progress in practice.

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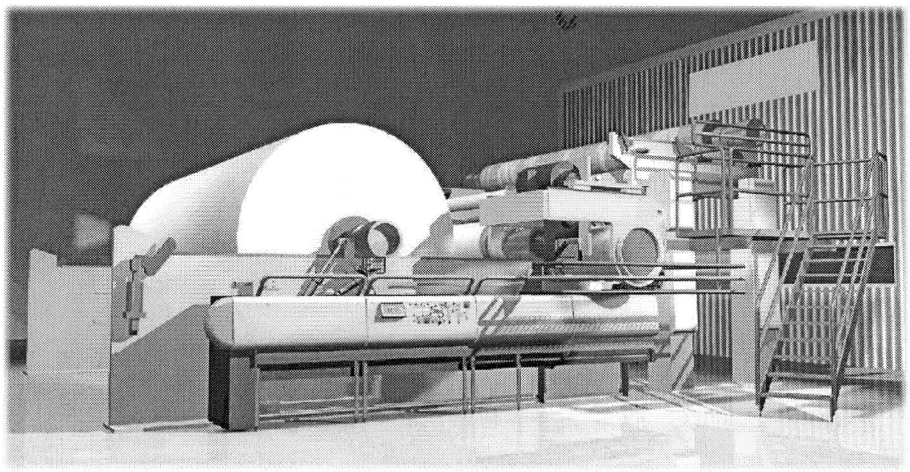

Figure 1. A modern second generation rell

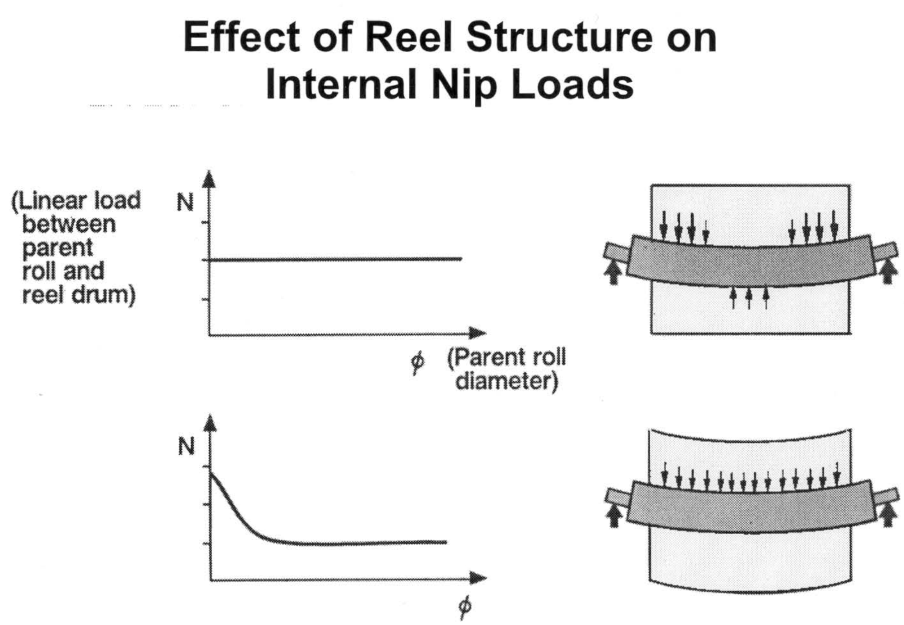

Figure 2. Effect of reel structure to internal contact loads.

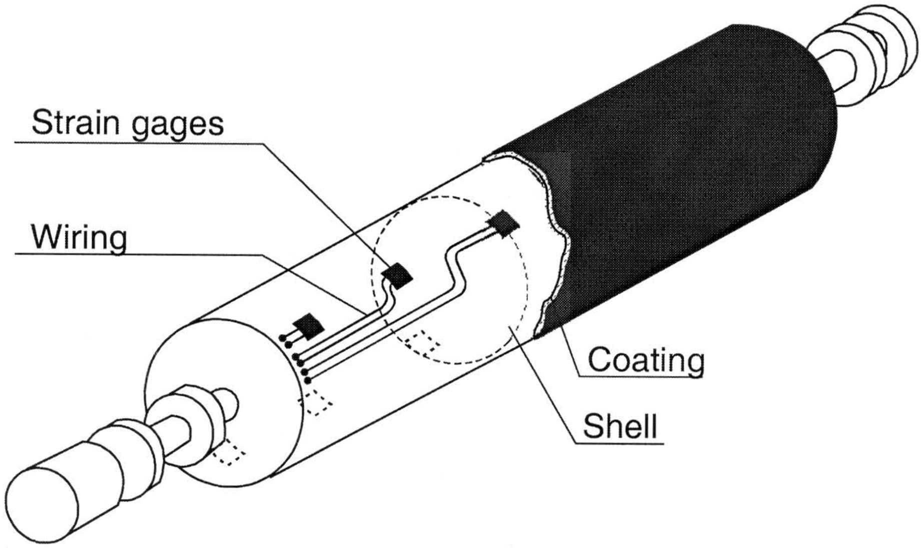

Figure 3. Location of strain gages in the reel spool

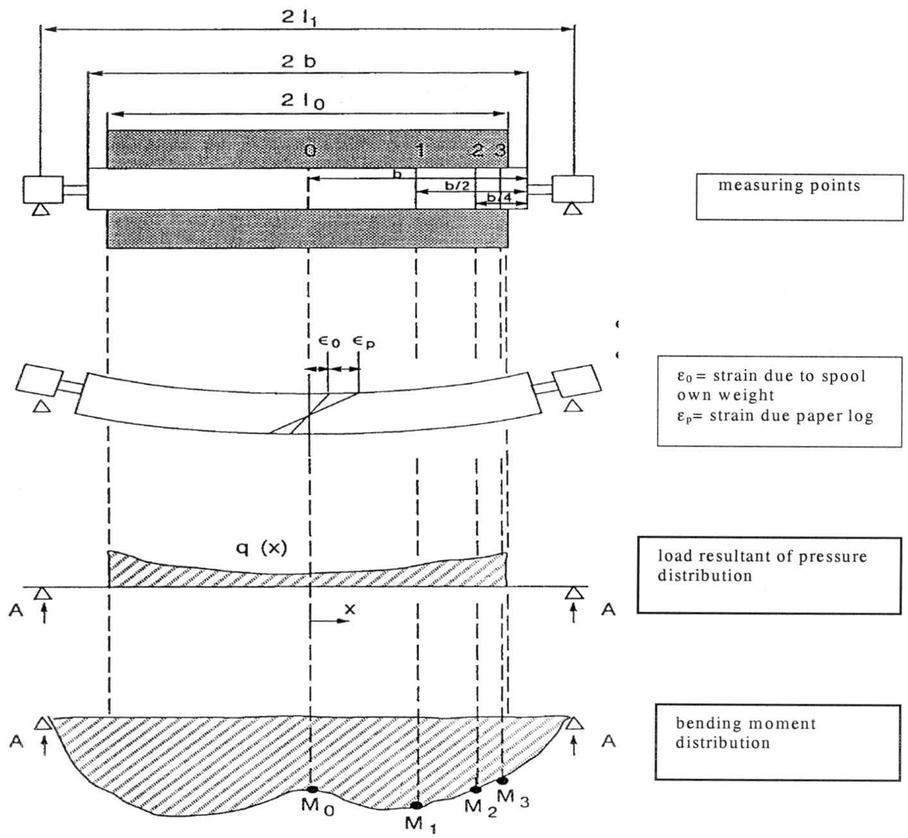

Figure 4. Measurement and calculation principle.

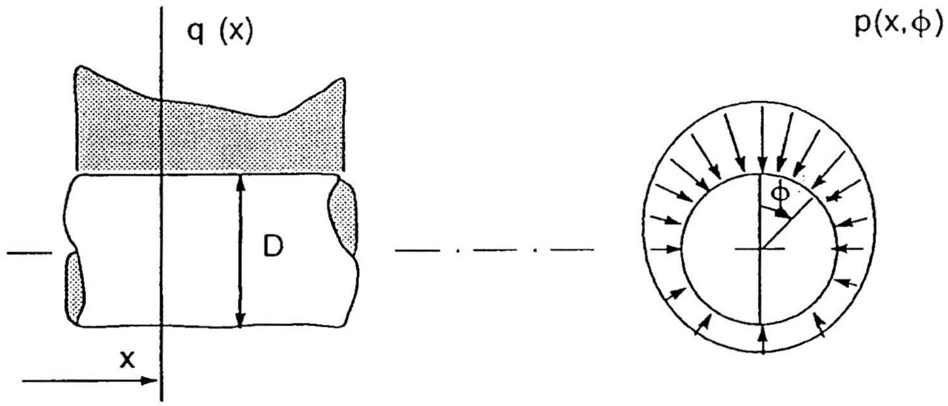

Figure 5. Assumed pressure distribution on the reel spool surface.

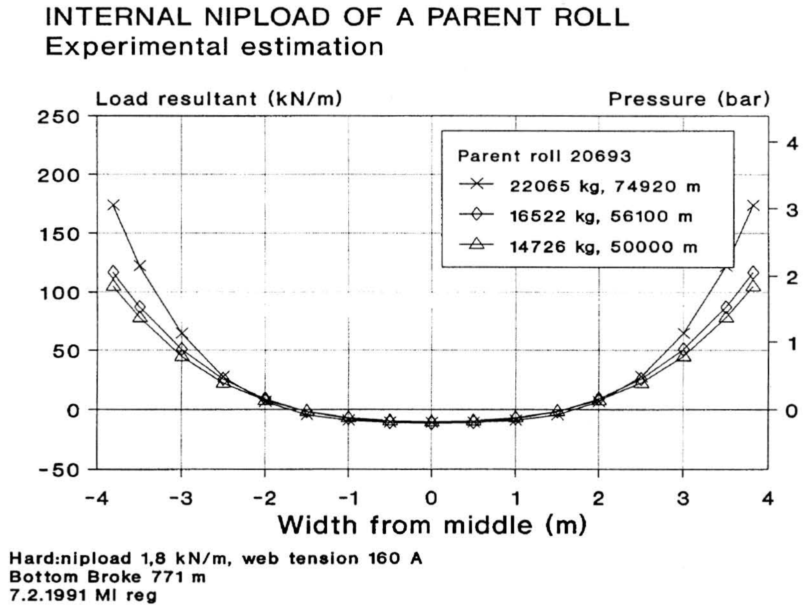

Figure 6. Hard reel measurement results

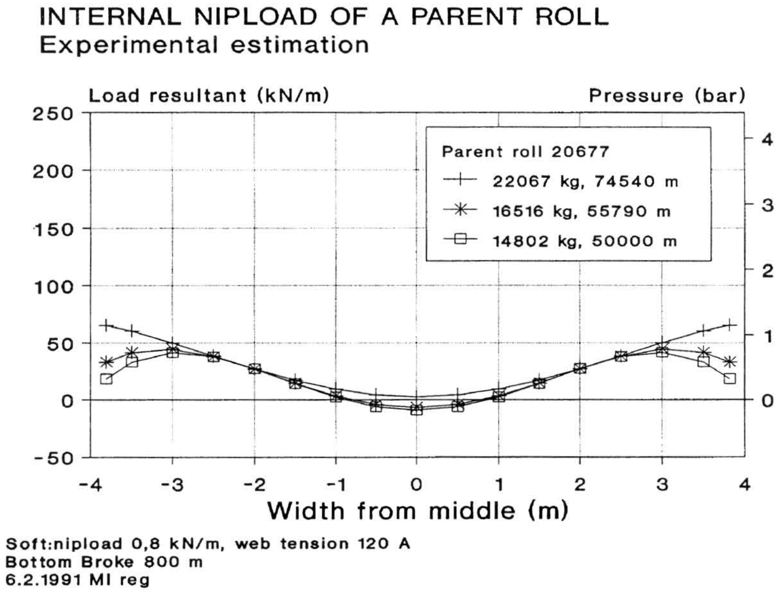

Figure 7. Hard reel measurement results

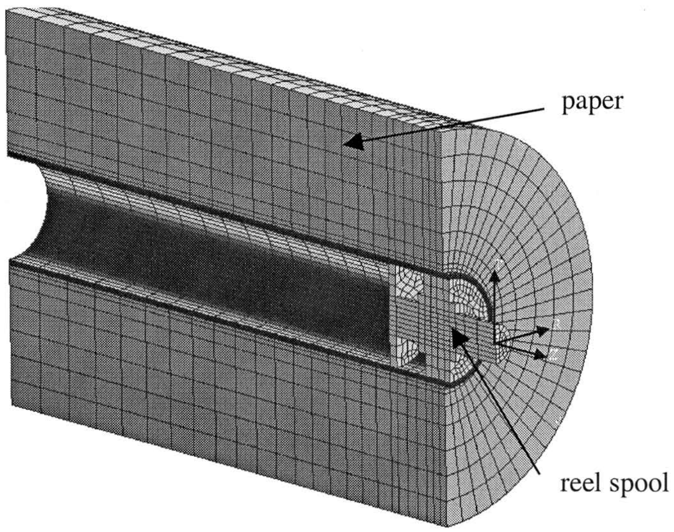

Figure. 8 FE model

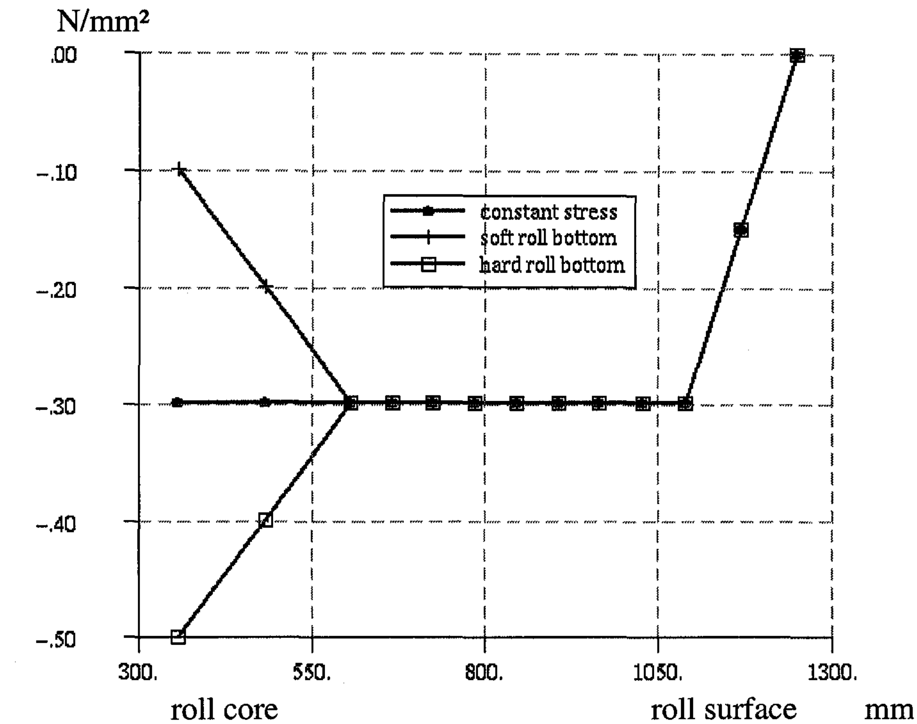

Figure. 9 Reel structure without gravity effect

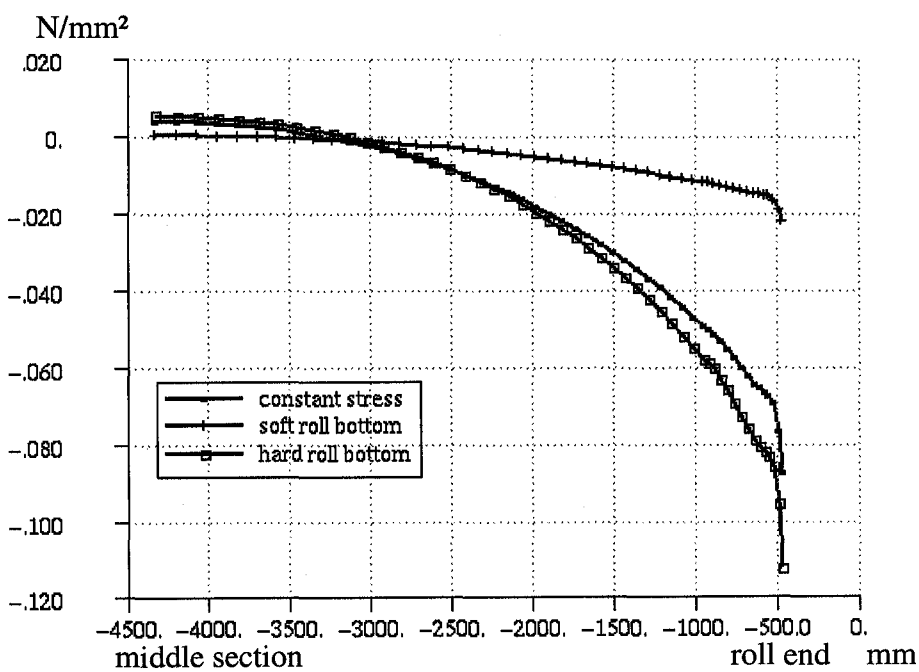

Figure. 10 Radial stress distribution

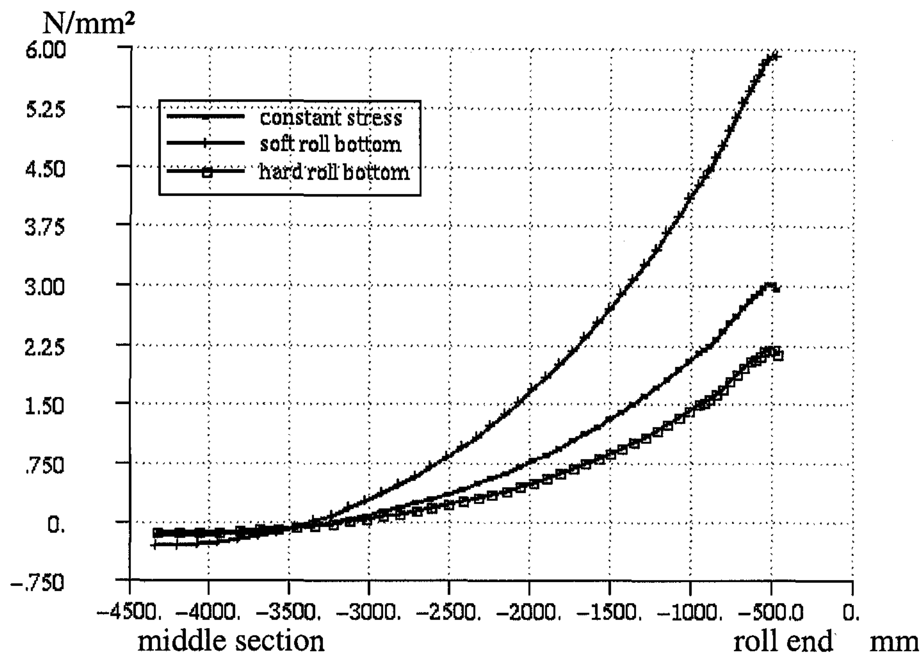

Figure. 11 Tangential stress distribution

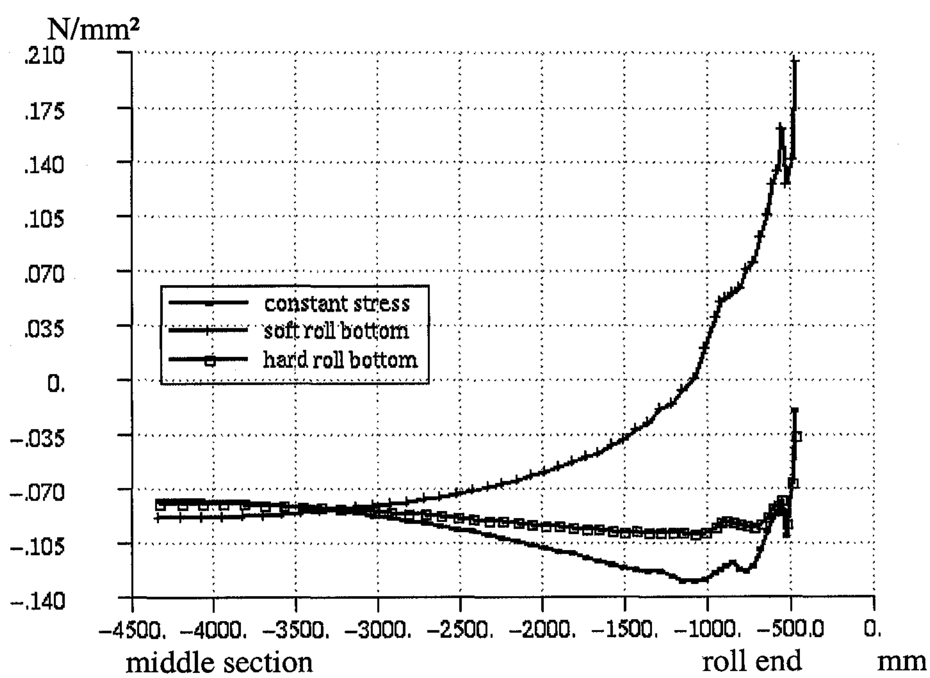

Figure. 12 Axial stress distribution

Experimental and Numerical Studies of the Reelspool and the Parent Roll Interaction Under Gravity Forces

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Name & Affiliation	Question
Y. Wang – Sonoco Products Company	You mentioned that you used contact boundary conditions, Where is the contact boundary condition applied? Between the reel spool surface and the paper roll?
Name & Affiliation	**Answer**
Matti Innala – Metso Paper, Inc., Finland	Yes.
Name & Affiliation	**Question**
Y. Wang – Sonoco Products Company	You applied the contact boundary condition, but you also said that you assumed the pressure distribution on the reel spool surface. So if you apply the contact boundary condition, why do you have to assume the load distribution?
Name & Affiliation	**Answer**
Matti Innala – Metso Paper, Inc., Finland	We knew the distribution from earlier experimental work.