THE BEST ELEVATOR ROPE

Ir. P. Kampers
United Ropes, Verto Wire Rope Division
P.O.Box 4090
2980 GB Ridderkerk, The Netherlands

1 ABSTRACT

The steel wire rope is an essential construction element for elevator manufacturers. The fabrication of elevator ropes to meet the demands of the elevator, result in a special product being made by the rope manufacturer. Owing to the use of traction sheaves, there are a number of contradictory requirements such as material hardness, size tolerance, stretch, fatigue, minimising sheave and rope wear and tear. In rope design the number of strands, wires per strand and the type of core (steel, natural fibre or synthetic material) can be varied. The influence of the latest variables on fatigue, stretch and damping properties of elevator ropes were tested.

2 PREFACE

About a hundredandforty years ago the first elevators were introduced. Eventhough a lot has changed in this kind of industry, still the traditional steel wire rope with a natural fibre core has been maintained.
In the elevator industry as well as the steel wire rope industry the use of natural fibres is under strong discussion because of the great natural variability in quality of these fibres and also the great difficulties to obtain the best fibres.
A test program has been set up by the University of Delft, Dr.Ir. L. Wiek, together with United Ropes (Verto Wire Rope Division). Tests were performed, the results of which may give some insight into which course should be pursued in future (1).

3 INTRODUCTION

Changing speed between traction sheave and steel wire rope always causes wear out of one of the two or both of them.
This wear of steelrope wires resp. traction sheave is a combined action of different variables:

1. contact pressure
2. hardness of sheave resp. kind of material
3. hardness of outerwires of the rope
4. lubrication
5. rope construction.

3.1 Contact pressure

Formulas have been developed for the different types of grooves, by which, for every elevator installation the contact pressure can be calculated.
The maximum allowed pressure is speed dependent. Already in 1927 (2) this has been made public in the diagram of Hijmans and Hellborn (see

fig. 1).
They proved that during intensive use of the elevator the contact pressure has to become lower to obtain an acceptable life time of the rope.

This figure also includes the line of the following formula:

$$p \leq \frac{12{,}5 + 4v}{1 + v} \qquad (\mathit{EN} - 81)$$

in which p is pressure (N/mm^2) and v is speed (m/s).

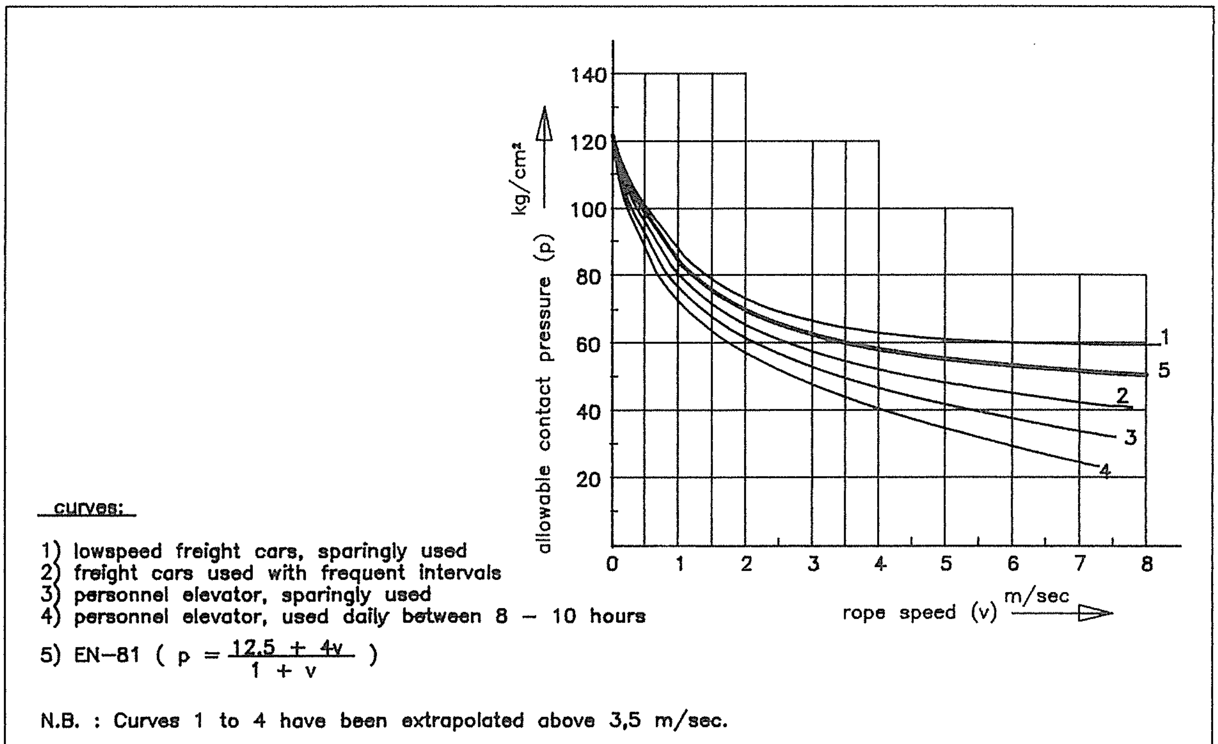

Fig.: 1 allowable contact pressure between rope and traction sheave

3.2&3.3 Hardness of sheave, kind of material and outerwires.

Wear of wirerope resp. sheave as a function of contact pressure, hardness of sheave resp. outerwire of the rope has been examined thoroughly by Mitsubishi (3). The authors also showed how wear can be influenced by variation of the material of the sheave, from cast iron to ductile nodular iron.

3.4 Lubrication

What should not be forgotten is the influence of lubrication. When a rope is bent, the wires and strands slide along each other and increased wear will take place at the contact areas. To reduce this internal wear a thin coat of grease has to be applied between the wires and the core.

University of Stuttgart (4) estimates that the endurance of a non-greased rope towards a greased rope at the bending fatigue is approximately 15%. The grease acts at the same time as a lubricant against external wear and corrosion.

3.5 Rope construction

For a decrease in the contact pressure, one should use a more circular rope, which can be achieved by a larger number of strands. For a reasonable tension distribution in the strands separately, it is a must to keep the number of strands even (5). For hoist application an eight-strand rope has proved itself to be better than a six-strand rope.
With the construction of the strands, a compromise between fatigue and wear will always have to be made. Concerning elevator ropes, the compromise will be between 9 and 12 outer wires per strand.
Another compromise in the design of an hoist-rope has to be made between fatigue life and elongation (stretch).

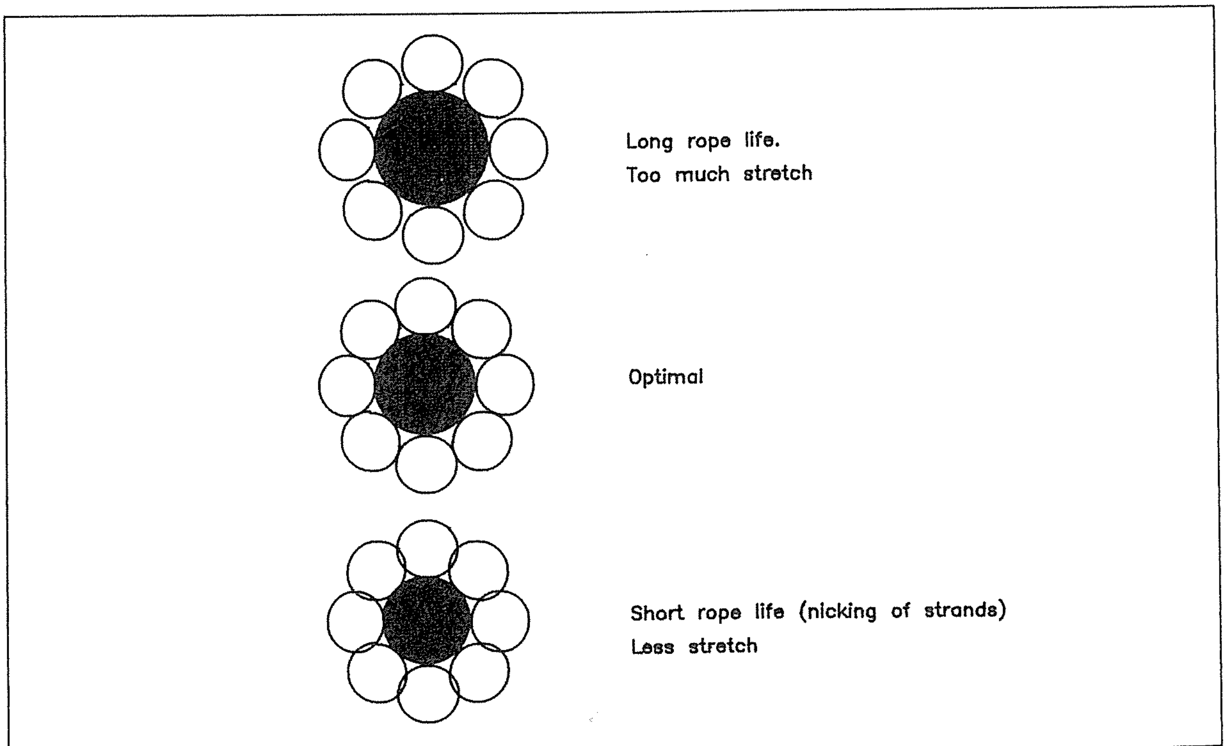

Fig.: 2 design of the rope

From the next 3 rope cross sections (fig. 2) it will be clear that number 1 has a long fatigue life with the most stretch. More often shortening of the rope will be the result. Number 3 will have less stretch but the rope life will be short due to nicking of the strands with many wire breaks. At the end the strand will break.
As variable in rope construction in the following test program, the rope core is chosen with a 8 x 19 Seale construction.

4 TEST PROGRAM

The bending fatigue of pull loaded ropes over sheaves is a phenomenon existing as a combination of wear, material fatigue and fretting corrosion. In laboratories one can investigate this on special machines. In this case we used the REFMA-machine of the University of Delft. The main parameters of these tests are:

1. the load of the rope. This can be defined as the ratio of the minimum breakingforce of the rope and the maximum workingload of the rope (factor of use =k) ;
2. the ratio of sheave diameter D towards the nominal rope diameter d (D/d-ratio).

For elevator ropes factors of use of 10 to 12 with D/d of 40 upto 50 are customary, this leads to extremely high rope lifes.
Under these conditions laboratory investigations are endless and therefore cannot be realized.
However, if the abovementioned two conditions are changed in such a way that shorter lifetime will be achieved, the circumstances will be totally different from the normal use of elevator ropes. This means that with these tests highly different degeneration processes will be responsible for the shortening of the rope life. Therefore results of these tests will not be reliable enough to give an answer as to which rope-core will be the best for elevator ropes. Simultaneous practical tests have to be done to affirm the results.
In search of the right setup of the testing conditions, we cannot refer to experiences of the past. We searched for the phenomenon of inner wear, which takes place at small bending of ropes under low loadings. This phenomenon becomes visible as oxidized fine metal parts, also called red rust.

This all resulted in the following minimum testing conditions:

a. D/d ratio of 25 with k = 5,16
b. D/d ratio of 40 with k = 4

In order to get a test program comparable with the elevator industry we have chosen the circumstances as mentioned under condition b.
Besides testing on bending fatigue on halfround grooves, we also did fatigue testing on sheaves with the halfround groove and an undercut (70 to 73% of the diameter).

5 ROPE TYPES USED

All ropes used are 8 x 19 Seale construction, right regular lay, dual tensile (1370/1770 N/mm²). In the right column the minimum breaking forces of the different ropes are shown.

The cores used are:

8 mm:	M.B.F. (kN)
- sisal	28,1
- polypropylene	28,1
- double parallel with polypropylene core	37,7
- double parallel with steelstrand	40,3

16 mm:

- sisal 113
- polypropylene 113
- Deltaflex (polypropylene and polyester) 113
- double parallel with polypropylene core 151
- double parallel with steelstrand 162
- steelcore (IWRC) 146

The cross sections of the different constructions have been given in fig. 3.

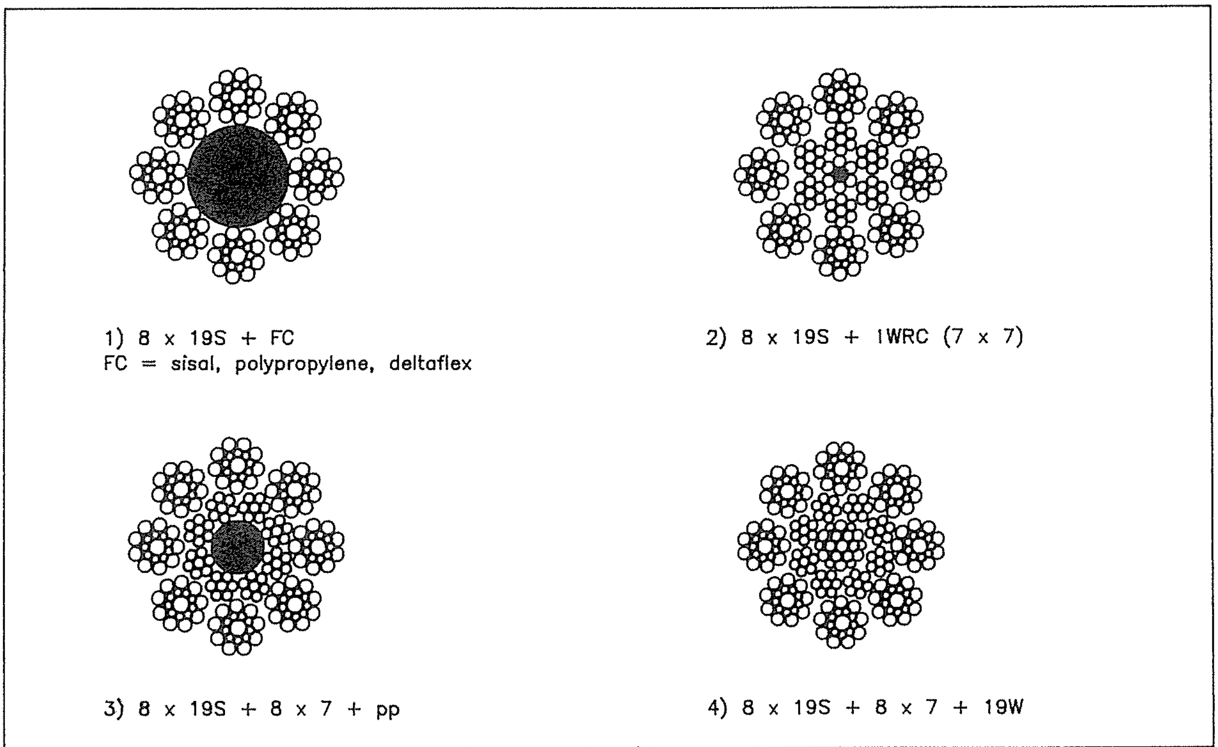

Fig.: 3 cross sections of different used rope constructions

6 TEST RESULTS FOR BENDING FATIGUE

<u>6.1 Sisal core : D/d = 25, d = 8 mm</u>
The results have been given in table 1.

Factor of use	Number of bends
12	2.294.400
8	676.927
5,16	242.353
4	60.493
3,22	23.077

Table 1

Up to test k = 5,16 the presence of red rust shows internal wear, which will be the mechanism of degeneration.

6.2 Sisal core: D/d = 40, d = 8 mm

Factor of use	Number of bends
4 3,22	520.259 148.843

Table 2.

Only when k = 4 red rust and internal wear was found. With k = 3,22 there was no internal wear and the rope was mainly damaged at the outer surface.

6.3 Ropes with D/d = 40, k = 4, d = 8 mm

The test results of ropes with different types of core and groove have been given in table 3.

Core material	Number of bends (U-groove)	Number of bends (Undercut U-groove)	Ratio
Sisal	520.259	396.162	0,76
Polypropylene	177.869	227.117	1,28
DP + pp	106.411	169.557	1,59
IWRC	82.761	93.702	1,13

Table 3.

6.4 Ropes with D/d = 40, k = 4, d = 16 mm

Core material	Number of bends (U-groove)	Number of bends (Undercut U-groove)	Ratio
Sisal	187.736	141.142	0,75
Polypropylene	191.772	141.990	0,74
Deltaflex	502.822	239.762	0,48
DP + pp	281.204	125.812	0,45
DP + strand	262.785	147.845	0,61
IWRC	142.520	86.500	0,56

Table 4.

6.5 Lubrication

One of the ropes (8 mm, IWRC) is examined on bending fatigue for a second time. However, this time the testing was stopped after each 15.000 cycles in order to lubricate the rope on the bending area. The lubrication used was a penetrating oil. The results show an almost four times longer life time of the rope and above all no red rust appeared.

Rope with D/d = 40, k = 4, d = 8 mm (Undercut U-groove)

Result of first test:	93.702 bends
Result after lubrication:	384.444 bends

7 TEST RESULTS FOR STRETCH AND DAMPING

From the different types of ropes and diameters load-elongation curves are determined carefully. As example see figure 4.
The structural stretch of the ropes can be determined by measuring the largest distance of A. The values, in percentages, are shown in table 5.

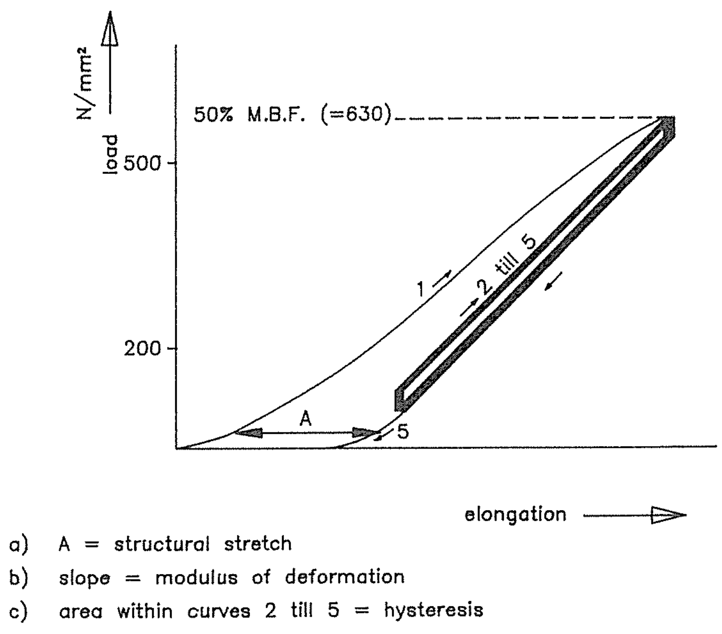

Fig.: 4 load–elongation curve (5 times)

Rope diameter (mm)	Sisal	Poly-propylene	Delta-flex	DP+pp	DP+ strand	IWRC
8	0,60	0,69		0,20		0,32
10	0,42	0,38		0,14		0,26
11	0,37	0,37		0,19		0,35
12						0,21
12,7	0,33					
13	0,34	0,33	0,56	0,21	0,16	0,25
16	0,25	0,22	0,40	0,17	0,10	0,18

Table 5.

Damping is a derivative of the hysteresis of the load-elongation curve. This hysteresis can be determined by measuring the area between curves 2 till 5.
The values in Joules (2,4m test length and 5% to 45% of the M.B.F.) are shown in table 6.

Rope diameter (mm)	Sisal	Poly-propylene	Delta-flex	DP+pp	DP+ strand	IWRC
8	21	21		20		24
10	34	27		22		37
11	30	29		32		45
12						
12,7	47					
13	39	41	85	55	50	54
16	58	73	78	76	61	76

Table 6.

8 DISCUSSION

8.1 Bending Fatigue

8.1.1 All tests were performed singly. From experience on the REFMA machine however the deviation in range of the amount of bends are maximum + and - 12 % of the mean values.

8.1.2 All ropes used for testing were examples taken from regular production, this means all kinds of varieties are possible.

8.1.3 For ropes with diameters of 8 mm the great differences between ropes with the fibre core resp. cores from steel wires in the half round grooves are remarkable.
Differences became smaller by using an undercut groove but evenso the good results of the sisal cores remained striking.

8.1.4 For ropes with diameters of 16 mm the good results of the ropes

with hard synthetic core (Deltaflex) towards ropes with sisal or polypropylene cores are remarkable. Explanation has to be found in the fact that when doubling of the diameter of the rope the radial forces on the core increase quadratically, this means a fourfold increase. Both sisal and polypropylene seems to be less resistant to this forces.
Double parallel is a good second one, it is significantly better than the traditional IWRC. The lower results of the last one surely will be caused by internal wear. The friction on the crossings of outer- and innerstrands will cause more damage in these ropes.

8.2 Structural stretch

There seems to be a small dependence on diameter, which however, can also be explained by the manufacturing of the ropes. Thicker ropes can be produced more regular and simpler than thinner ones. That structural stretch with softer cores will be larger than the stretch with hard cores seems to be a trivial statement.

8.3 Damping

The hysteresis of ropes with hard cores is larger than with soft cores. An exception is the Deltaflex core, which, also in absolute figures, showed the largest hysteresis. In elevator installations this will also have the greatest effect on damping.

9 CONCLUSIONS

9.1 The EN-81 formula for maximum allowed contact pressure needs to contain a variable in which the intensity of the use of the elevator will be included.

9.2 The achieved results of these laboratory tests will have to be verified by practical tests, because especially the traction parameter could not be simulated in these tests.

9.3 Seen from design, materials used and production an elevator rope is a highly critical rope, for which, dependent on the use and kind of installation, a compromise has to be made between stretch, damping and bending fatigue.

9.4 For thinner ropes (8 mm) the sisal as core fibre seems to be much better than all other core materials. For 16 mm ropes the harder synthetic fibre (Deltaflex) gives motives for further testing.

9.5 If, by reasons of lower structural stretch and better damping qualities, one decides for steel cores instead of fibre cores, double parallel is preferred over IWRC. In all cases the IWRC showed the worst bending fatigue results.

9.6 Lubrication of elevator ropes has a positive effect on the life time of the rope, at the same time it also prevents formation of red rust.

10 LITERATURE

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11 BIOGRAPHICAL NOTES

Pieter Kampers graduated as metallurgical engineer at the Technical University of Delft in 1970. For 10 years he worked at the two existing Steelcompanies in the Netherlands in different positions. He has been working for United Ropes for the past 12 years and currently holds the position of Technical manager for the Wire Rope Division.