Some Aspects of Wire Ropes for Material Handling Ropeways
M. Clayton, London, United Kingdom

SUMMARY.

A single broken wire in the outer layer of a fully locked construction track rope will normally stay in, but deterioration soon takes place and two or three adjacent broken wires can provoke a major accident. The vulnerability of the track rope on material handling ropeways is described in a case of a high capacity rope of the most advanced design, where also the ropemaker took all the care to produce a good rope.

Over 14 km length of this rope the forty five mostly single wire breaks may not be a large number but did create a great deal of inconvenience and expense. All this occurred within one year of operation and became a source of potential danger. The only correlating factor of these wire breaks is their location, always at the entry of the track rope onto the saddles and on the top of the rope, as otherwise they occurred at random places. Fatigue failure was diagnosed as the cause of the wire breaks resulting from the rolling action of the carriage wheels and obviously of a particular behaviour of the track rope in the afflicted places. Awareness of the possibility of such occurrence is important for the industry and some guiding lines are put forward.

A very special and important application of wire rope is for the track of industrial ropeways and constitutes a significant component not only because it is costly but the efficiency of the whole plant is linked to it's satisfactory performance.

In high transport capacity ropeways the track ropes are heavily stressed and require particular attention in respect of design, manufacture and working conditions.

However many will agree that notwithstanding all the care and perseverance to respect the best practice, rules and regulations the track rope, often surprisingly, does become the source of concern and disappointment.

It is such an aspect of the track rope behaviour which I intend to describe in this paper to draw attention to it's vulnerability to usually unexpected factors, further emphasized by the unique, first off, character of the plant in consideration.

In fact this is a third paper on this subject, the first describing a case of early track rope failure on industrial ropeways and the second on a break up of track rope due to vibration, both given in C.I.P.E.B.C. proceedings.

The premature break up of the track ropes in the first case resulted from fractures of the outer layer shaped wires, followed by round wires breaks in the core and it was caused by secondary bending fatigue and fretting corrosion.

The main reason for this failure was found in the wrong selection of rope construction, of only single layer shaped wire over round wire center, and faulty sizing of wires resulting in inadequate design clearance between shaped wires.

In the second case, of most intensive break up of track rope which can be attributed only to vibrations, this took place close to a perfectly normal anchorage set up and by no means could have been anticipated and still remains a mystery.

ROPeway DETAILS.

The ropeway in question of superb modern design is 14 km long, in 3 units, traverses hilly country and the line is supported on 64 trestles, with an average span of 218 m, but many spans reach 400 m and more. This ropeway with a transport capacity of 600 T/hr operates at the speed of 5 m/sec and to provide the best working conditions for the track ropes the saddles lined with plastic material are of the fixed type, perfectly fitted into the carefully designed rope profile.

The ropeway car weighs with load 3000 kg and the clip pressure, resultant from the weight of the hauling rope lifted by the carriage grip, reaches 1520 kg, therefore the maximum pressure of a carriage wheel is of the order of 1130 kg, which is a moderate pressure for a nylon lined wheel.
The total duty of the track rope is to support the transit of 300 cars per hour and as each car runs on 4 wheels, every point of the rope is subjected to 1200 flexing cycles per hour.

It is certainly a demanding duty, by the intensity of traffic, of about 5 million per year, however, this size of the track rope, its quality and construction and the applied tension was deemed to be adequate for the duty.

**TRACK ROPE DETAILS.**

The full side track rope, which is the subject of our considerations is 63 mm in diameter, of fully locked construction (14+12+18+24+30 center. +29 Z first layer +34 Z outside layer). The center wire is 4.1 mm diameter, the round wires 3.75 mm, the first layer Z wires 5.2 mm and the outside layer wires 5.5 mm, all bright steel.

The total cross section is 2632 square mm of which 38.2% forms the center 26.6% the first layer, and 35.2% the outside layer wires. The aggregate breaking strength of the rope 18 364.430 kg, weight per m is 22.27 kg including grease, with tolerance of ±5%.

The tensile strength of the wires is of relatively low order 150 kg/square mm for the 3 wires and 140 kg/square mm for the round wires.

The production of this rope was carried out under strict control, both by the manufacturer and also myself. The standard checks of the wires before and after closing confirmed characteristics well above the stipulated limits. The three test pieces subjected to a traction break reached 339 tons, a rope closing loss of only 6.9%, which indicates that clearly all the wires in all the layers must have participated in development of the full breaking strength of the rope. This feature gives also some indication as to correctness of closing of the rope.

A check of the sum of the widths of the heads of the outside layer Z wires comes to 0.977 of the circumference of the rope which indicates that there is no danger of tubing of this layer.

Examination of the surface of the rope during manufacture and on completion did not disclose any irregularities.

The track rope is divided into 7 sections each anchored at one end and tensioned at the other by means of a floating weight. The applied tension initially varied between 92 - 96 tons, giving a ratio of wheel load to tension on the line of around 1 : 60.

While the appearance of the empty side of the track rope on the line was perfectly regular, the full side track rope showed some slight waviness in some sections and some small gaps between the wires on the surface were visible.

**FULL SIDE TRACK ROPE DEFICIENCY.**

The ropeway commenced operation in February 82. On the 20th of October 82 resulting from a derailment of a car at trestle 37 four Z wires of the outer layer got broken and were immediately repaired by welding (brazing). However, soon afterwards new broken wires were noticed, all on top side of the rope reposing on saddles at a distance of about 1.20 - 1.60 m from the entrance to the saddle, where the rope makes contact with the saddles liner on entry of a loaded car. By the end of February 83 twenty five broken wires were counted in sections 2, 4, 6, and 7 of the line on twelve trestles.

In the section 1, 3 and 5, wire breaks did not develop. The major number of twelve broken wires occurred in section 4 where the rope shows some waviness and irregularities on the surface. Slight looseness of wires coinciding with trestles 32 and 37 was also observed. In section 7 similar blemishes were noted and seven broken wires counted. Section 6 had four broken wires and section 2 only two.

All wire breaks, with the exception of only one found on the exit side of the saddle, were positioned on the entry side of the saddle corresponding with the area where the helix of the fractured wires is held by the saddle liner.

This would indicate that in the first instance some looseness in the outer wire have existed in the affected places, which under repetitive rolling action of the carriage wheels, ended in flexing of these not perfectly supported wires and held by the saddle liner, producing what is called secondary bending fatigue. The working of the rope where the wire breaks took place vary in respect of rope pressure on the saddle, rope incline, bend over angle and clip pressure, but the rolling action of the carriage wheels is similar at each trestle in it's effect. Obviously on trestle saddles where the rolling action of the carriage wheels did not produce wire breaks, which is about 85% of the total number of trestles, conditions leading to secondary bending fatigue of the outside wires did not exist.

It is clear that the only correlating factors are the position of the wire breaks and their characters, to confirm this reasoning.

The micrographic investigations into the mechanism of the wire breaks disclosed that the starting point of the wire break was in a zone on the side of the Z wire just above the waist in in every case. There were no signs of any wear between the wires at this point which confirms that the tubing effect
was not in question. Neither the quality of the steel wires was questioned. Four samples of wire breaks were examined by electron scanning photographs of the surface of the typical fatigue wire breaks are given in Pl. 1-4.

At this stage the ropemaker having investigated in great depth this serious, but limited deficiency came to the conclusion that the cause of this rope behaviour cannot be attributed to the manufacturing process itself, but to some extraneous reasons. Remedial action decided upon consisted of:

1. Increase in tension of the full side track rope. A check of the line calculations indicated a possibility of increase of tension well by 10 tons.

2. Investigation of the possibility of closing or releasing to some extent the outer layer of the rope.

3. Repair by welding (brazing) of broken wires.

4. Transposition of the rope in accordance with the terms of the guaranty.

By March the increase of tension weights by 10 tons which also produced a small transposition of the rope over trestles was completed. A marked slow down in the increase of wire breaks was noted; but by June in section 4, the most affected, the number of broken wires reached twenty five on 8 trestles, more than double the initial number. In section 2, the number of broken wires increased to five and in section 7 to ten, also the double of the initial number. The wire breaks have by the month of June 83 taken place on 16 trestles which is on 28% of the total number of the trestles. By August 83 - out of the total of forty five broken wires, thirty were repaired by welding, mostly with replacement wire. The wire repairs involved 56 welds. In some cases replacement of a single wire eliminated two breaks. During the repairs some replacement wires had to moved so as to distribute the welds over longer lengths. Major difficulties for this reason were encountered on trestle 37 where eight wires were broken, three from precedent repairs, and where the welds had to be distributed over the length of 40 m.

These repairs can be considered as satisfactory and have left the rope in a stable condition. On the rope from section 4, the most affected by wire breaks, it was eventually noticed that the rope lay varied from 590 mm at the anchorage end to 610 mm towards the outerweight. In view of this, it was considered advisable to try small release by 2 turns of the closure of the outer layer which resulted in some small elongation of the reduced lay.

The nominal lay of the rope is 600 mm which is automatically built into the processing of the rope.

The section of the rope Nr. 7 where the rope lay was correct throughout it's length was subjected to 15 cloring turns of the outer layer. This resulted in turning a little of the track rope surface on the saddles.

Further experiments in this direction were not proceeded with, due to their limited effectiveness.

DISCUSSION.

Notwithstanding the great care and effort of the ropemaker of considerable experience and the enlightened approach of the ropeway designer to provide the best working conditions for the track rope, its behaviour in ropeway operation, to complete surprise of all concerned turned out to be not only unsatisfactory but also negating some of the procedures which should have ensured satisfaction.

It cuts across the working life guaranty of 18000 hours given by the ropemaker and ropeway manufacturer. It is also a burden on the ropeway operation.

This track rope deficiency is above all very difficult to explain, it is still a big question mark in some respect.

Having had assurance from the ropemaker of homogeneity of both the inner material and the manufacturing process why out of 7 sections three have not been affected by wire breaks and in the rest only at 28% of the trestles. Why only some single wires in random places could not withstand this duty imposed by the passing car.

There is no question of a fatigue failure of the whole rope, which has life expectation of at least 20 million bending cycles. Here we have a fatigue failure of single wires resulting from the rolling action of the carriage wheels, which in a reverse way act as detector of the weak spots on the line as well.

But why when according to all the rules available, which we hear that have been respected, the track rope should have behaved as a rope and not as a bunch of wires which can be easily broken.

So as not to have a repeat of the same failure to the decencement of another ropeway user we have somehow to find an answer to this dilemma.

Let's therefore have a look at the facts once again.

The duty imposed on the reasonably well tensioned track rope, supported on correctly dimensioned saddles, is that of the passage of carriage wheels, every 12 seconds, with a maximum single wheel load of 1150 kg. The ropeway operates for 4000 to 5000 hours per year which induces by each passing wheel 4,800,000 to 6,000,000 bending cycles.
The break up of the forty-five wires developed over a period of about 4500 hours of operation.

The across wire breaks have been already recognised as secondary bending fatigue breaks with some evidence of torsion forces present. This kind of break could only take place if the wire became somewhat loose, which on the one hand can be linked to the rolling action of the carriage wheels, but on the other the condition of the rope must have allowed for it to happen. In other words the support of that single broken wire over the second layer must have been inadequate and the behaviour of the core may have been a contributory factor.

It is significant that the described misfortune has been observed by the ropemaker for the first time, although, of course, secondary bending fatigue is frequently encountered in track rope failure.

It must also be acknowledged that a new element of higher intensity of service came into play; we have here a passage of the car at every 12 seconds for 20 hours per day. The support of the track rope on relatively long fixed saddles is another new factor, which evidently has a holding effect for any creeping movement of the outer layer wires under the rolling action of the carriage wheels.

Both the ropemaker and the ropeway designer were fully aware of the need to respond with proper technological approach to the increased demands imposed upon the track rope. Certainly some small irregularities of the surface of the track rope in the section afflicted by the wire breaks were observed and perhaps these may relate to the loosening of the broken wires, but there is no definite proof.

The ropeway as a whole, the first of its kind, is a complete success, while at least some sections of the full side track rope remain a problem and in some ways an open question.

Some conclusions and guiding lines can however be drawn to prevent similar misfortunes in the future.

1. While the use of the liners on carriage wheels has eliminated the destructive effect of the very high contact pressure of the steel carriage wheels on the outside layer of the track rope, it remains vulnerable and as in our case to unexpected factors.

2. The rolling action of the carriage wheels on the surface of the track rope on high capacity and high intensity ropeways must be taken into consideration.

3. The high pressures, if present, on the supporting saddles which may lead to some deformation (ovalisation) of the track rope must be countered by adequate and rigid rope construction.

4. Attention should be given to accuracy of drawing of the profiled wires so as to ensure an equal distribution of pressure.

5. An adequate tension will help to encourage a good support between the wire layers of the track rope.

6. For the ropeway design, taking note of the experience gained, it could be advisable to consider also the use of other than fully locked constructions, for example half lock where the greater adherence between the layers and some other features could be of advantage.

Finally it is worth remembering and having in mind the catalogue of track rope failures, that a freak feature of a specific rope application may cut across our carefully studied norms, standards and formulas.

Such occurrences for the sake of safety of operation should be given publicity and indeed they form a part of the complexity of the wire endurance problem.
FIGURES 1-4: Micrographic investigations showing aspects of the surface of the wire breaks with the starting point always in the wire waist, magnified 30 and 1000 times.