

The Importance of the Visual Inspection for Ropeway Ropes

George A. Kopanakis
Control Body ICRS

Past scientific officer at the “Institute of Lightweight structures and Ropeways” at the Federal Institute of Technology in Zurich (CH), head of the department “Ropeways Engineering” of IWM Glattbrugg (CH)

Since 1999: Independent technical consultant for the rope industry, the ropeway operators, the ropeway industry, the elevator industry, the industry of rope propelled amusement rides, ropeway associations and ropeway authorities

Since 2008: CTO of the Control Body ICRS (Swiss **I**ntercantonal **C**oncordate of **R**opeways and **S**kilifts)

Other professional activities:

Since 1994: Member of the management board of the OIPEEC

Since 1997: Expert witness in the state of Baden Württemberg (Germany)

Since 1999: Member of the OITAF Committee No. II: Characteristic and inspection of ropes



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by George A. Kopanakis¹

A dramatic incident at the Schilthorn, a renowned ski area in Switzerland, almost ended up in a fatal disaster. The sudden loss of more than 50% of the metallic cross-section of a locked coil track rope due to a deterioration mechanism unknown within rope and ropeway professional circles (Hydrogen Induced Stress Corrosion Cracking “HISCC”), roused the whole ropeway community!

Thorough visual inspections subsequently carried out on aerial trams of similar build, brought to light the existence of surface damage in an unexpected high number of track ropes.

The current paper

- summarizes briefly the incident
- shows the importance of the visual inspection as a part of the maintenance procedures
- explains the goals of the visual rope inspection
- shows how visual inspection should be carried out and
- finally points out and explains the fact that the visual rope inspection and the magneto inductive rope testing methods are complementary and therefore they cannot substitute each other.

¹ Job Title:	CTO
Company Name:	Control Body ICRS (Intercantonal Concordat for Ropeways and Skilifts)
Address:	Zeughausstrasse 19
City, Postal Code, Country:	CH - 3860 Meiringen, Switzerland
Phone:	+41 33 972 30 00
Fax:	+41 33 972 30 01
Cell:	+41 79 402 69 81
E-mail	kopanakis@ikss.ch or george.a@kopanakis.eu



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Introduction

The “Schilthorn” Incident

On December 29th, 2004, at approx. 1:44 PM, cabin no. 3 of the Mürren-Birg aerial tramway was situated, on its upward journey, just below Birg top station when a loud “metallic” noise was suddenly heard. The inspection that was carried out immediately afterwards revealed that all the outer wires on rope B were broken. The tramway was immediately taken out of service and the passengers were evacuated by helicopter; nobody was injured.

The metallic cross-section of the broken outer wire layer corresponded, on these older rope designs, to approx. 55% of the entire metallic cross-section. In addition to that, it is important at this point to underline the fact that the core of the rope apparently remaining undamaged became unlayered because of the lack of the outer layer and the ensuing loss of torque balance resulted in an unequal load distribution among the remaining wires. For this reason, it may be presumed that the remaining safety factor was not significantly higher than 1.

Signs of galling, abrasion and corrosion were found on the rope surface along the damaged section of rope. The material (steel) which had been deposited on the rope surface during the process of galling originated from the deflection saddle of the rope at the top station. The rope section which was found to be damaged after the incident was bent exactly over this deflection saddle in the top station during the first 14 years of operation.



Fig. 1: View of the damaged



Fig. 2: Damaged area with signs of galling

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Address:	Zeughausstrasse 19
City, Postal Code, Country:	CH - 3860 Meiringen, Switzerland
Phone:	+41 33 972 30 00
Fax:	+41 33 972 30 01
Cell:	+41 79 402 69 81
E-mail	kopanakis@ikss.ch or george.a@kopanakis.eu

During the first relocation procedure -14 years after the opening of the system and 26 years before the incident- the rope slipped abruptly over the deflection saddle under great surface pressure. During this process both the rope, as well as the groove of the deflection saddle, were mechanically damaged. The decisive factor leading to the spontaneous breaking of the entire outer wire layer was, in the final analysis, the hydrogen induced stress corrosion cracking “HISCC” detected along the area of the above-mentioned damage, which led to brittleness of the material and to micro cracks.

Relevant operational data of the track rope

- 1965: Opening of the aerial ropeway
- 1979: 1st relocation of the track rope
- 1991: 2nd relocation of the track rope
- 2003: 3rd relocation of the track rope

Relevant technical details

- The material of the deflection saddle was steel
- The ratio of the radius of the deflection saddle to the rope diameter (R/d) was approx. 50
- The radius of the groove was greater than that of the rope
- As the relocation of the carrying rope took place, loud metallic noises (slip-stick) were heard
- After the first relocation and on the basis of the reports available, the rope was checked visually 25 times
- After the relocation and on the basis of the reports available, the rope was magneto inductive tested 9 times, the latest test being 6 months before the incident

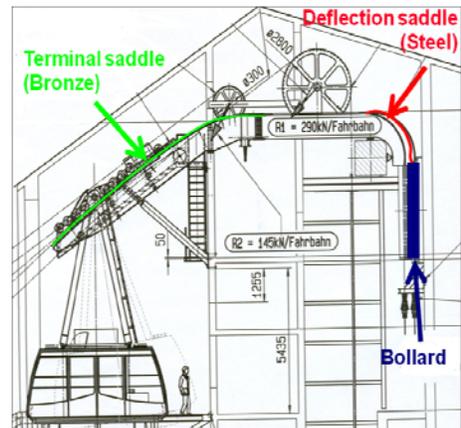


Fig. 3: Rope area bent over the deflection saddle (red)

The catastrophe was avoided due to

- the impeccable behaviour of the “residual rope”
- the exemplary vigilance and reaction of the ropeway staff

The surface damage occurred due to

- Design / Production deficiencies
 - The material of the deflection saddle, or, the combination of the material of the rope and that of the saddle adversely influenced the sliding properties of the rope over the saddle
 - The ratio $R/d \sim 50$ (instead of 65 as stipulated in the current EN standards), resulting in a higher pressure between the rope and the saddle
 - The fact that the groove radius was greater than the rope radius resulted in a higher pressure between the rope and the saddle

- The absence of a “third body” (lubrication) between rope and saddle adversely influenced the sliding properties of the rope over the saddle
- The lack of instructions on the part of the system manufacturer regarding the relocation process
- The lack of expertise on the part of the company which carried out the rope relocation

Reasons why the surface damage was not recognised early enough or reasons for the apparent failure of the indented “safety net” respectively

- The inability to recognize such a type of damage by means of a magneto-inductive test combined with the erroneous belief that a magneto inductive test is able to do just that.
⇒ Inability to recognize and respect limits
- The fact that those responsible within the operating company as well as the company which carried out the rope relocation ignored the loud metallic noises heard during the first relocation.
⇒ Lack of awareness
- The ignorance - which is on the increase in recent years - of the significance of, or the dangers arising from any damage occurring on the rope surface and the thereof resulting demand for a clean rope surface as well as for a thorough visual inspection.
⇒ Lack of knowledge
- Poorly carried out visual inspections due to the dirty rope surface and the lack of sensitivity to this type of damage.
⇒ Lack of awareness and knowledge

Reasons for the untypical development of the rope degradation (the spontaneous breakage of the wires) and for the extent of the damage (all outer wires.)

- Hydrogen induced stress corrosion cracking in combination with the concomitant lengthy “incubation period” and the fact that this type of deterioration mechanism, although well known in many other technical fields, was completely unknown within rope and ropeway professional circles.

To sum up, this incident plainly showed that besides the avoidance of technical deficiencies, the reestablishment of the importance and need of a correctly carried out inspection should be of highest priority.

Already in 2006 some activities have been started aiming to improve -in medium and long term- the detected deficiencies within the field of rope inspection. These activities are currently continued in the OITAF Committee No. II (Characteristics and inspection of ropes) under the responsibility of the FOT (Swiss Federal Office of Transport / Urs Amiet) and the ICRS (Swiss Intercantonal Concordat for Ropeways & Skilifts / George A. Kopanakis)



Maintenance

Maintenance includes all actions which have the objective of, respectively, retaining an item in, or restoring to, a state in which it can perform its required function in order to:

- retain or improve safety
- prevent any unscheduled interruption of operation
- optimize service life
- improve the availability of the system
- optimize the operating procedures
- reduce malfunctions
- budget correctly

Maintenance consists of:

- service
- inspection, and
- overhauling and repair

Inspection

The list of all the maintenance aims clearly demonstrates and underlines its importance. Therefore, and taking into account the fact that inspection is the only maintenance tool by means of which possible defects can be detected at all, it is evident that the inspection itself is particularly important.

The word “inspection” comes from the Latin and, translated literally, means, particularly in technical fields, “to look into”.

The aims of properly carried out inspection are:

- Determination of the current condition
- Assessment of the diagnosed condition
- Determination of the reasons which are responsible for any deviation from the nominal condition
- Decision upon the necessary steps to be carried out in order to ensure the reestablishment of the nominal condition, respectively, the safe and trouble free operation



Inspection of Ropeway Ropes in General

Everything mentioned above is also valid, of course, for ropes which are used in the field of ropeways, particularly as ropes are safety elements!

For the inspection of ropeway ropes, the following non-destructive tests are available for use:

- Magneto-inductive or radiographic test, and
- Visual inspection supplemented with additional measurements

The magneto inductive or the radiographic tests may only be carried out by personnel specially trained and approved, using special equipment. These tests are carried out by independent bodies authorised to perform this task at intervals of time laid down by the authorities or whenever else on particular demand as for example, when an incident occurs. The visual inspections and their according frequency are officially regulated as well. However, the latter can be carried out by employees of the ropeway operator. (See EN 12927-7)

The Visual Inspection of Ropeway Ropes

As is well known, ropes are “long” subsystems. Accordingly, it goes without saying that a visual inspection of such a part, on account of its very length, will prove to be difficult. For example, a visual inspection of a three-kilometre long track rope performed conscientiously by two employees at an inspection speed of 0.3 m/sec takes about 2 $\frac{3}{4}$ hours without a break. Approximately 11 hours would be needed for all four track ropes. And that is without taking into consideration the tiredness that creeps in when looking closely at the moving rope, the generally unfavourable working position, the potentially adverse weather and visibility conditions, the possibly difficult access to the rope, the often not very clean rope surface and, not least, the potential danger of injury.

It thus becomes obvious that for a visual rope inspection to be carried out correctly, a “quick look along” is not enough.

Determining the actual state of a rope

In order to be able to determine the actual state of a rope, first of all, the following questions must be answered conclusively:

- **“Who?”** *Who performs the visual examination?*

For a person carrying out an inspection (inspector) to be able to recognise changes to the external (and, under certain circumstances, partly to the internal) condition of a rope, a minimum amount of experience is required. In addition, and because the visual inspection is a “comparing” inspection, in which the attempt is being made to determine deviations from the initial, or nominal condition, it is necessary to have the inspection always done by the same person, as far as possible.



The demands made on the inspector in terms of his ability to see properly as well as his physical and mental state will not be further discussed here. They are, however, a basic prerequisite.

- **“Where?”** *Are all areas of the rope to be treated in the same way, or should certain parts be given particular attention?*

Basically, the whole length of the rope must be visually inspected! It is, however, important to pay correspondingly even greater attention to the areas of the rope which are particularly endangered. These are:

- Within the splice area: The tucks, the area of the tucked tails and the tucked tail ends
- The areas of the rope end connections
- Areas where the rope has been clamped
- Areas which are under higher stress, such as the part of the rope which is flexed over a roller chain, the tensioning ropes, the parts of the track rope which are flexed over saddles, etc.
- Areas which are particularly exposed to corrosion
- Areas which, as a result of malfunctioning or manipulation, have been mechanically damaged. For example, surface damages occurring when a rope strikes against the adjacent structure or those caused during installation work due to slipping clamps, etc.
- Areas which have been damaged as the result of an accident or a storm (for example, when struck by lightning).
- etcetera

The above list is by no means exhaustive and should be completed by the respective operators, depending on their own specific experience and boundary conditions.

- **“How?”** : How is the inspection to be carried out?
 - To be able to inspect a rope visually, the basic prerequisites must first of all be fulfilled, namely, that the *surface of the rope* is actually recognisable. And that can only be guaranteed if the rope surface is *clean*. This goal can most easily be achieved if, from the very beginning, the rope surface is kept clean by regular cleaning. If this is neglected, it can easily happen that cleaning with simple cleaning methods is no longer possible. Should this be the case, it is urgently recommended that the rope manufacturer should be consulted. No attempt should be made to remove the dirt with sharp, mechanical, or chemical products, since there is the danger of damaging the rope permanently.

Regarding this point, it should be also noted that, according to the standard (EN-12927-6 Figure 5.2.1) the following is valid: Quotation: “Ropes shall be discarded if their condition cannot, or can no longer, be assessed with the current methods of inspection.” Taking into consideration the fact that, since the “Schilthorn” incident at the latest, it is common knowledge that the evidence provided by the magneto-inductive test alone is not



sufficiently rigorous, this means, if we are to be entirely consistent, that a *completely filthy and encrusted rope has to be discarded*.

- When longish sections of rope are to be examined, two inspectors should be involved in order to make sure that -at least nearly- the entire surface of the rope is covered visually. For this purpose, good access to the observation point of the moving ropes or a special platform for the stationary ropes is absolutely essential.
- The relative speeds of rope and inspector may not exceed 0.3 m/sec (According to EN 12927-7, 0.5 m/sec are allowed), so that the recognition of possible irregularities is guaranteed.
- The visual inspection should be conducted in dry weather and with good visibility, so that details of the surface are clearly visible.
- The inspector should make sure that all safety precautions are taken, particularly in the case of an examination of a moving rope (for example, a hauling rope).
- Any material which easily unthreads (e.g., a lady's stocking or a cleaning cloth), when wound around the rope and then drawn along it during the visual inspection, is a simple aid for the recognition of external wire breaks as well as of some kind of surface damage.
- Every spot where damage, or any other kind of problem has been detected, must be marked in such a way as to resist both weather and abrasion. In addition the distance of the damaged spot from a fixed reference point has to be measured and documented thereby ensuring the easy retrieval of the detected damage at a later date.
- Part of a visual inspection is the measurement of the diameter of the rope and its lay length. The measurements should be taken both in free rope areas as well as in the vicinity of singularities such as the splice or any end connection. They should, every time, be taken preferably at the same spots in order to make sure that a genuine comparison between two inspections can be performed.
- Tools necessary for carrying out the visual inspection are: A spring tape measure, marking material, a calliper with flat jaws, a tool for measuring the lay length (a ruler mounted onto an angle profile so as to make sure the ruler is parallel to the rope axis), a magnifying glass, a mirror, as well as cleaning materials, rags and lubricant. Finally, writing materials and a camera are needed to document the found condition. On the premise that the person conducting the inspection is experienced enough, it is recommended that fine sandpaper be taken along so that any minor surface damage can be removed on the spot. However, care should be taken that the sanding direction remains always parallel to the axis of the wire. As a basic principle, repairs of greater areas of damage may only be carried out by the rope manufacturer or by any qualified person. Of particular importance is that the loss of diameter and consequently the loss of metallic cross-section due to the sanding process should not simply be disregarded.



- If, during an inspection, a localised cleaning operation has been necessary, it is most very important to re-lubricate the according spot at the end of the inspection.

At the Institute for Materials-Handling Technology and Logistics of the University of Stuttgart, a device to support visual inspections has been developed with which a large part of the difficulties involving a visual inspection have been eliminated, such as, for example, the inability to see the whole surface, the restricted vision resulting from changing or bad visibility, tiredness which sets in during the inspection, the lack of documentation resources or the potential danger of an occupational accident. With the help of this device, the rope surface is given high contrast illumination and is, at the same time filmed by four high resolution cameras which are arranged around the rope. The entire surface of the rope is thus initially stored. The actual visual inspection can then be carried out at a later time and in “office conditions” on a screen and by a single person. In addition, the inspection can be interrupted at any time, if need be, and continued again later. (For any inquiries: Institute for Materials-Handling Technology and Logistics of the University of Stuttgart / winter@ift.uni-stuttgart.de)

- **“What?”** : What can be detected by means of the visual inspection?

The following deviations from the initial or nominal condition can be detected with the help of a rigorously conducted visual inspection.

- External wire breaks and, in certain circumstances, signs of an accumulation of internal breaks.
- Loose wires
- External corrosion and, under certain circumstances, signs of advanced inner corrosion.
- External wear
- Deterioration of the external rope structure
- Changes in the lay length and diameter.
- Mechanical damage
- Changes in the microstructure of the wire material due to unusual thermal conditions, in so far as changes in colour are present.

Assessment of the diagnosed condition

To be able to evaluate the current condition of a rope, the following are the basic prerequisites:

- Competence/Experience
- Information regarding the rope
 - Rope specification sheet
 - Past history / old records
- Knowledge of the regulations, in particular the applicable discard criteria.



The answers to the following questions are necessary in order to be able to assess the condition of the rope:

- Has any loss of metallic area^{a)} occurred? At this point it has to be underlined once more that loose wires count as broken!
- How are the wire breaks distributed along the rope length?
- Can any internal damage be expected, and is therefore a non-destructive test necessary?
- Has the strength of a rope area which is in the immediate vicinity of a damaged spot and which appears unchanged equally been impaired (for example, an area of rope next to a spot affected by a lightning strike or any other source of heat)?
- Are the discard criteria applicable?
- Is the damage likely to develop further?
- Are immediate measures necessary?
- Does the according authority have to be informed?

Determination of the reasons responsible for the deviation from the nominal condition

It is often necessary to determine the cause of damage so that the detected damage can be correctly assessed at all. In particular, questions which concern the potential further development of the damage or the measures necessary to be taken can be answered conclusively only in connection with the determination of the cause of the damage. To achieve this aim of the inspection, exact knowledge must be gained about:

- a): Thoughts and methods regarding the calculation of the loss of metallic cross-section and the according difficulties to be expected can be found in the paper: "Estimation of the loss of cross-section of wire ropes" 2008, Dr. Stefan Messmer
- the rope itself
 - the installation
 - the operation, as well as
 - any possibly unusual sequence of events which have occurred



Decision upon the necessary steps to be carried out in order to ensure a trouble free operation

Assuming that the condition of the rope has been assessed conclusively and the cause of the damage determined, the necessary measures may be decided upon and employed as the basis for repairs to be carried out by specialists.

However, it is entirely possible that sometimes the assessment of the damage, the determination of the causes as well as the conclusions arrived at about consequences turn out to be difficult and complex respectively. In these cases, it is recommended that the advice of an external technical expert be sought.

Concluding remarks

With the help of *properly carried out magneto-inductive or radiographic tests*, the detection of *external or internal damage* which is connected to an abrupt change of the metallic area is possible within physical limits. In general, the detectable damages, in the field of ropeways, are mainly wire breaks. In addition, advanced internal corrosion, inner wear and, under very specific conditions, (the quality of the equipment used, the experience of the inspector and the availability of results from previous tests) a damage which is perpendicular to the rope axis (for example, scratches) can be detected as well.

However, with the help of a *thoroughly carried out visual inspection*, not only the detection of broken outer wires is possible but also loose wires or any external mechanical damage, which could not be detected by means of a magneto-inductive test. Thus the visual inspection enables the early recognition of impending damage, and contributes, together with the correctly performed repair, to the avoidance, or at least to a reduction of the extent, of the damage.

This means that there are types of defects which can be detected with the help of only one of the two inspection methods. *It is thus obvious that the two types of inspection complement, and therefore cannot replace, each other.* For this reason, the attempt, for example, to increase the frequency of magneto-inductive tests with the intention, of reducing in return, the frequency of visual inspections is *erroneous*.

For an operator blessed by luck the consequence of this misconception might only be a material damage and the there from resulting financial loss. For the one who is less lucky, though, the injury or even the death of fellow humans can be the sobering consequence.

