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Failure analysis of a ropeway accident focussing on the wire rope's fracture load under lateral pressure

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A B S T R A C T

The bi-cable reversible aerial ropeway had been built as a winch system exclusively for goods transport. During upwards transport the winch was brusquely stopped by the operator. This caused the winch rope to slack and eventually to fracture at the moment of the jerky stretching by the backward rolling carriage. The brakeless carriage sped downhill along the track rope and finally crashed into the lower station leading to the unfortunate death of the farmer sitting unlawfully in the carriage. The steel wire rope (∅6 mm, type 6 × 7-FC) showed no indication of the typical failure mechanism of moving ropes, i.e. fretting fatigue. The single wires were broken in almost the same cross section showing a mixture of conical and shear fractures. This unusual fracture pattern could have been either the consequence of a local pre-damage or of an excessive lateral pressure and bending at the cross point of two windings on the winch. The latter alternative was evaluated by a test setup, allowing continuous increase of the deflection angle β until fracture of the rope.

As a rule of thumb for $\beta < 25°$, the deflection angle in degree is numerically roughly equal to the caused load capacity reduction of the rope in percentage, e.g. a deflection angle of 10° reduces the load capacity by approximately 10%. Based on this empiric relationship, along with the calculated critical back-roll velocity of the carriage, it could be proven that the jerkily stretched rope could have fractured without being necessarily pre-damaged.

The quantified susceptibility of the rope's ultimate load to lateral pressure at sharp bending can also support future investigations of similar failure cases and risk analyses.

1. Introduction

Statistically, areal ropeways are one of the safest transportation systems [1,2]. In particular, rope fractures rarely occur, thanks to a high level of inherent redundancy provided by its construction, made up of stranded single wires [3]. The condition of the rope is monitored periodically with regards to wear and fatigue thus allowing the rope to be replaced before the residual load capacity would become critical [4]. With this background, the ropeway accident in focus of the present paper, caused by fast fracture of a winch rope, is peculiar.

The bi-cable reversible aerial ropeway was built in the 1970s as a winch system exclusively for goods transport (Fig. 1). The drive unit of the winch, consisting of a diesel engine, a gear transmission and a shoe brake, was located in the upper station and was operated by mechanical handles without an electrical control system. The carriage rolled between the upper and lower stations along the 1 km long stationary track rope which was supported by 3 pillars. During uphill transport, the winch rope pulled the carriage up with a velocity of up to 3 m/s. During downhill transport, the carriage was driven solely by gravity, while the winch rope acted only

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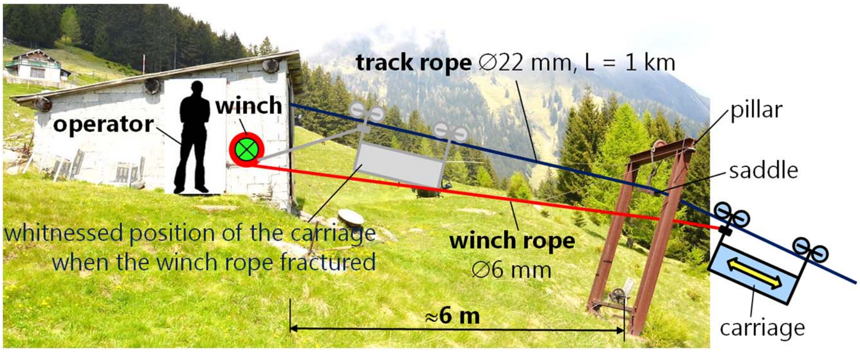

Fig. 1. Upper station of the ropeway with superimposed sketch.

as a speed regulator, transmitting the braking force from the drive unit to the carriage. In accordance to the more lenient regulations for freight ropeways [5] compared to ropeways for human transport [6], the carriage was not equipped with an emergency brake [7].

Before the accident, a farmer loaded the carriage in the lower station and unlawfully also sat in it. He instructed the operator of the winch by cell phone to pull up the carriage. As the carriage passed the last pillar, the operator was shocked to spot his colleague in the carriage and brusquely stopped the winch. The carriage rolled out due to the inertia forces almost touching the upper station, thereby causing a slack in the winch rope (Supp. 1). The carriage came to a stop. Then, the downhill force accelerated the carriage in the opposite direction. According to witnesses, after a backward rolling distance of the carriage by roughly 1 m the rope stretched again and in that moment it fractured. The brakeless carriage sped downwards along the track rope still carrying the farmer and eventually crashed into the lower station leading to his death.

Undoubtedly, the fracture was triggered by the dynamic load peak due to the inertial force of the backwards rolling carriage. However, it was crucial to clarify if additional negative factors, like a pre-damage of the rope or an additional extraordinary load significantly favoured the fracture.

2. Preliminary investigations

2.1. Fundamentals

For legal reasons, the judge ordered the failure analysis only two years after the accident. By that time the ropeway was fully replaced by a new one, therefore an onsite inspection was not possible. The only available fundamentals for the failure analysis were, besides court records, two sections of the winch rope; each with one fractured end, labelled by the police to be both sides of the same fracture (Fig. 2). In the present paper, these two rope sections and their fracture brushes are referred to as follows:

- W: winch side (uphill) section. This sample with an arbitrarily predefined cut length of 4 m was wrapped up from the winch by the police.
- C: carriage side (downhill) section. The un-fractured end of this rope section was directly attached to the crashed carriage. Therefore, the length of this remnant section (0.7 m) corresponds to the distance of the fracture from the carriage.

2.2. Macroscopic findings

The winch rope in common cross lay design has a nominal diameter of 6 mm (Fig. 3). The 6 strands are made up of 7 carbon steel wires each and are wrapped around a fibre core (e.g. design type: 6 × 7-FC).

The guaranteed fracture load for the nominal strength of the wires (grade) of 1960 MPa is F_g = 23.4 7kN [8]. The main visual

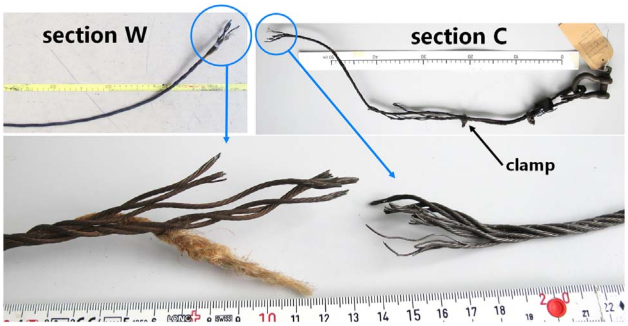

Fig. 2. Winch rope sections W and C with fracture brushes (circles). See also Supp. 3.Winch rope sections W and C with fracture brushes (circles). See also Supp. 3.

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