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SELECTION OF ZIPLINE BRAKING DEVICE

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Abstract

This paper provides the basis for the selection and calculation of the zipline braking and stopping devices. Considering that there is currently no legal regulation in Serbia that defines devices for zipline braking and arresting, an excerpt from some foreign standards are given in the first part of the paper. This is followed by an overview of existing solutions of arresting systems, as well as examples of patented solutions. In the second part of the paper, an calculation example for a concrete zipline and braking device is given.

Key words*: zipline, braking, stopping*

1 REGULATIONS ON BRAKNIG SYSTEMS

Based on the ACCT (*Association for Challenge Course Technology*) and ASTM (*American Society for Testing and Materials*) standards, for ziplines at which velocities above 10 km/h are achieved, it is necessary to provide adequate systems for safe stopping [1].

The ACCT standard distinguishes:

- Zip Line Brake System: A system that controls and/or arrests the motion of a person along a zip line. Brake systems can be active or passive.
- Brake System: An arrangement of primary and emergency brakes that are designed to function together to arrest the motion of a person.
- Primary Brake: The principal brake in a zip line brake system, engaged during normal operation to arrest a user's motion. Primary brakes include both gravity-assisted brakes and other brake force-generating devices.
- Emergency Brake: A brake located on a zip line that engages without any participant input upon failure of the primary brake in order to prevent serious injury or death.

On the other hand, the ASTM standard differs:

- Brake System: As it applies to aerial adventure courses, examples of braking systems include, but are not limited to: longitudinal friction brakes, disc or drum brakes, motor end brakes, either onboard or off-board of the patron-carrying vehicle or device. If the failure of the braking system results in an unsafe condition, then the braking system shall be fail-safe.
- Fail-Safe: Characteristic of an aerial adventure course, or component thereof, that is designed such that the normal and expected failure mode results in a safe condition.

2 SOLUTIONS OVERVIEW

The passenger is usually stopped at the end of the section by a bumper which is attached to the rope which is connected via an extension line with a certain braking device. The extension line can be connected directly to the arresting device, or a suitable mechanical adventage can be obtained by rewinding it, so a smaller device is needed.

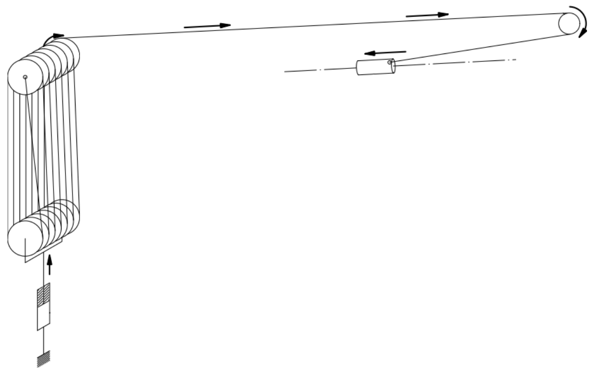

Fig. 1 *Arresting system with hydraulic brake*

Figure 1 shows a schematic representation of arresting system where the braking is performed by a hydraulic cylinder, while Figure 2 shows a system where the deceleration of passenger is done by attaching a bumper to a chain.

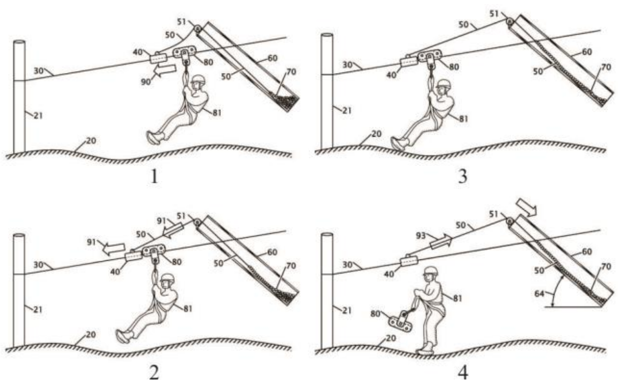

Fig. 2 *Arresting system with chain*

However, the mentioned solution with a chain can be seen in certain patent applications [2], but as far as the authors know, not in practice. In practice, the most common solution is with springs as given in the example shown in Figure 3. In this solution, the deceleration is performed by helical spring where the extension line can be directly connected to the bumper or it can be rewinded [3].

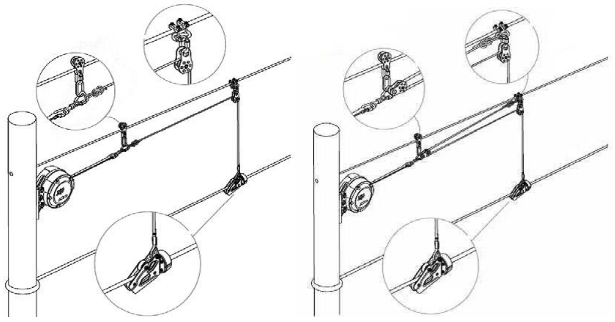

Fig. 3 *Arresting system with a spring*

Since the extension line which connects the bumper with the brake can't float in the air, an auxiliary rope must be provided. The extension line is at certain distances connected with auxiliary rope. Figure 4 (left) shows a solution with an auxiliary rope fastened to the pillar (so-called offset redirection), while Figure 4 (right) shows beam mounted pulley [3].

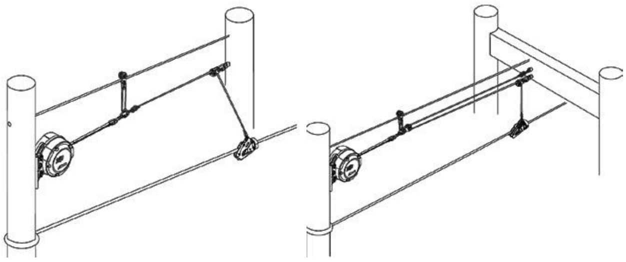

Fig. 4 *Offset Redirection Pulley and Beam Mounted Pulley*

If the slope of the rope at the lower pillar is such that the freely released trolley tends to approach the lower pillar, it is a positive slope [3]. If the freely released trolley tends to move away from the pillar, it is a negative slope.

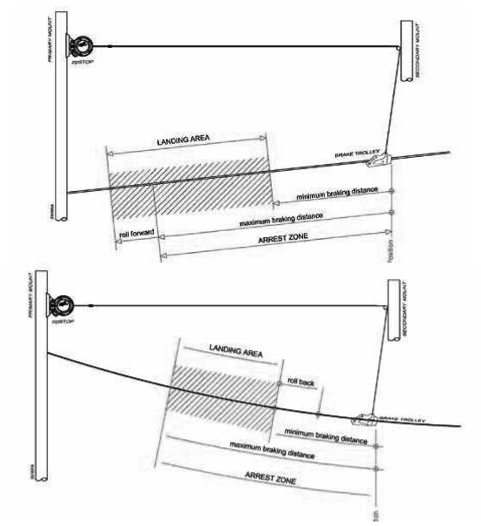

Fig. 5 *Positive and negative slope line*

For a section with a negative slope, it must be prevented that the trolley with passenger moves backward. This is achieved by using a brake trolley with catch mechanism. The working principle of those mechanisms can be seen in Figure 6.

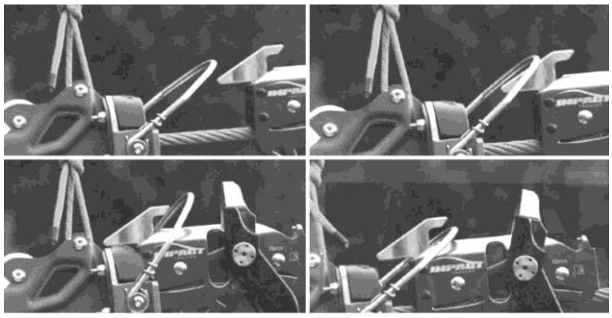

Fig. 6 *Brake trolley with catch mechanism*

Springs as shown in Figure 7 are most often used as an emergency brake at the end of zipline section.

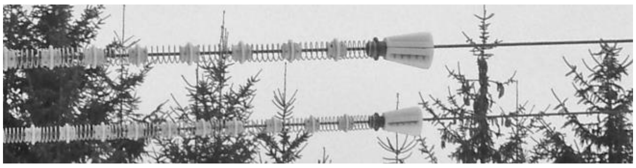

Fig. 7 *Springs as an emergency brake*

Solution shown in Figure 8 has brake in the form of a turbine filled with viscous fluid, while solution shown in Figure 9 has a brake in the form of an electromotor.

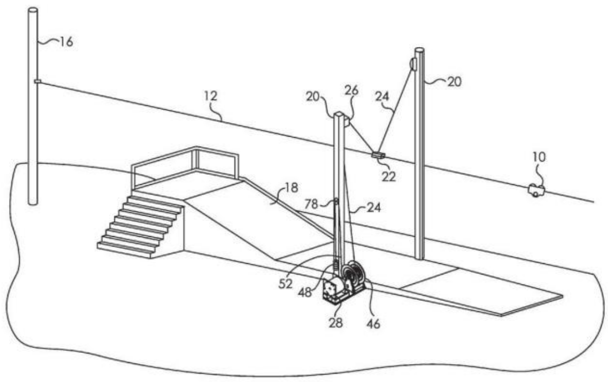

Fig. 8 *An example of a braking system [4]*

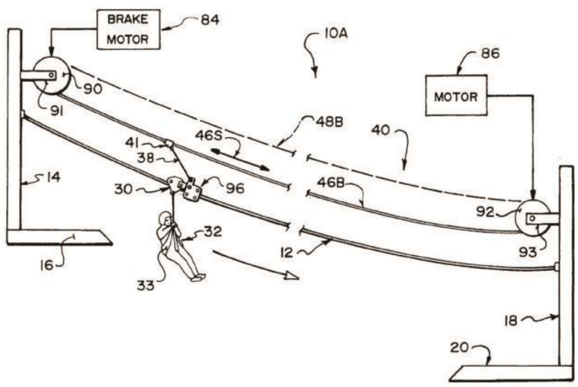

Fig. 9 *An example of a braking system with an electromotor [5]*

3 CALCULATION AND BASIS FOR BRAKING DEVICE SELECTION

Within this chapter an example of braking distance determination for braking device with helical spring will be shown.

Fig. 10 *Braking device*

Based on the recommendations which are detailed described in [6] and [7], it follows that the length of the braking distance is determined depending on the passenger's velocity at the end of the section, as well as the lowering position. The intensity of the braking force can generally be determined according to the formula:

$$G = \frac{F}{m \cdot g} = \frac{\frac{m \cdot v^2}{2 \cdot l}}{m \cdot g} = \frac{v^2}{2 \cdot l \cdot g} \quad (1)$$

where:

v – velocity at the end of a section,
l – braking distance,
g – gravitational constant.

The maximal allowed value of acceleration / deceleration depends on the passenger position and for case of a sitting position it is limited to 6g. However, since the passenger is connected to the trolley by belts which allow swinging in the direction of movement, a braking force of 6g will cause an upward swing and the passenger may hit the zipline cable. It has been empirically determined that the braking force should not exceed the intensity of 2,5g.

Observing the lowering of a trolley with two passengers in a sitting position which is detailed described in [7], and for which the bases are given in [8]-[11], following diagram of changes in horizontal velocity component is obtained.

Q_{min} and Q_{max} are representing minimal and maximal weight of two passengers, ammounting 130 kg and 200 kg.

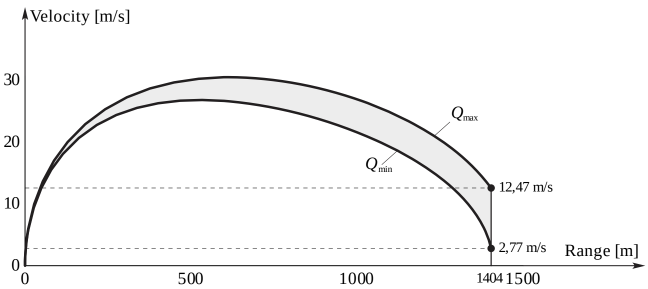

Fig. 11 *Diagramm of velocity*

If the desired G-force is known, tha braking distance can be calculated from Eq. (1) as:

$$l = \frac{v^2}{2 \cdot G \cdot g} \quad (2)$$

Table 1 shows required minimal and recommended braking distances for minimal and maximal weight which can occur on zipline. Values of braking distances are calculated in accordance with Eq. (2).

Table 1 Minimal and recommended braking distances

	v_{end}	$l_{G=6}$	$l_{G=2,5}$
Q_{min}	2,77 m/s	0,06 m	0,15 m
Q_{max}	12,47 m/s	1,32 m	3,17 m

However, considering that the usage of ziplines is allowed even in slightly windy weather, for the case of tailwind with an intensity of 6,5 m/s, the velocity diagram would look as shown in Figure 12.

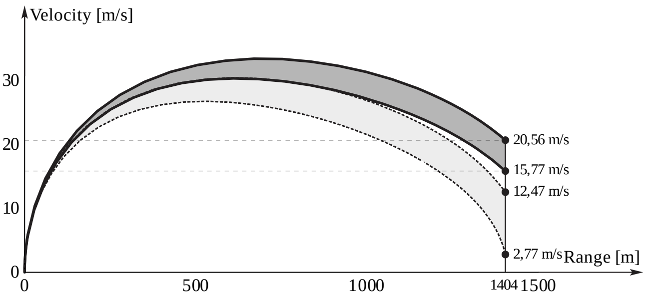

Fig. 12 *Diagramm of velocity for case of tailwind*

Table 2 shows required minimal and recommended braking distances for minimal and maximal weight which can occur on zipline for case of tailwind.

Table 2 Minimal and recommended braking distances for case of tailwind

	v_{end}	$l_{G=6}$	$l_{G=2,5}$
Q_{min}	15,77 m/s	2,11 m	5,07 m
Q_{max}	20,56 m/s	3,59 m	8,62 m

4 CONCLUSION

Keeping in mind that an increased number of long ziplines are being built lately, braking and stopping of passengers became more and more important. Recommendations for the selection and installation of an appropriate braking system are given by manufacturers of arresting devices, but for certain input data such as the velocity at the beginning of braking which must be determined by zipline designer.

The designer must also define the braking intensity, and one of his guidelines may be recommendations which are given in this paper.

The aim of this paper was, among other things, to show in how wide limits the desired values range. For chosen zipline, in addition to the mass and lowering position of the passenger, the huge influense has a possible wind. Lowering position influences the surface exposed to air-flow (and thus the final velocity) as well as the allowable *G*-force.

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