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Risk management on the strada statale del Tonale e della Mendola in the Roccette – tumortal area in the province of Bolzano

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The area known as 'delle roccette' on the Tonale and Mendola Road shortly after Passo Mendola is subject to rockfall, avalanche and debris flow events. To mitigate risks derived from natural hazards, structural and non-structural mitigation measures have been adopted, such as the establishment of an avalanche commission to provide decision-making support to the Road Service. The evaluation of both efficiency and effectiveness of the measures taken, has been validated by the degree of acceptability of residual risk of human life loss before and after mitigation strategies have been applied.

Keywords: *rockfall, avalanches, risk management, mitigation measures, acceptable risk, maintenance, avalanche commission.*

1. Strategic importance of the area

The Mendel Road connects the Bolzano (Bozen) basin and the Val di Non. During public holidays the road is mainly travelled by commuters, while people from Bolzano (Bozen) use the road on weekends to drive to their holiday homes. The only possible diversion leads trough the Val di Non and the Adige Valley, requiring an additional time of 75 minutes. The average daily traffic amounts around 4,000 passages/day. The presence of the funicular railway from Caldaro (Kaltern) to Passo Mendola (Mendelpass), which is also often closed due to snow, does not solve the commuters' inconvenience.

2. Exposure of the area to natural hazards

The summit of the Mendola chain consists of two types of dolomite. The upper part is characterized by the presence of the Sciliar Formation, while the lower part is formed by the Contrin Formation, which exhibits highly decompressed and fractured rocks.

The morphology of the slope is quite steep and consists of a succession of vertical walls and slopes with gradients of even more than 45%, cut by very steep gullies. This step-like morphology is characterized by the different compactness of the more or less horizontal sediment layers. The steep trenches essentially follow tectonic faults and a pervasive fracture system.

The Mendola Road cuts through the Contrin Formation, creating

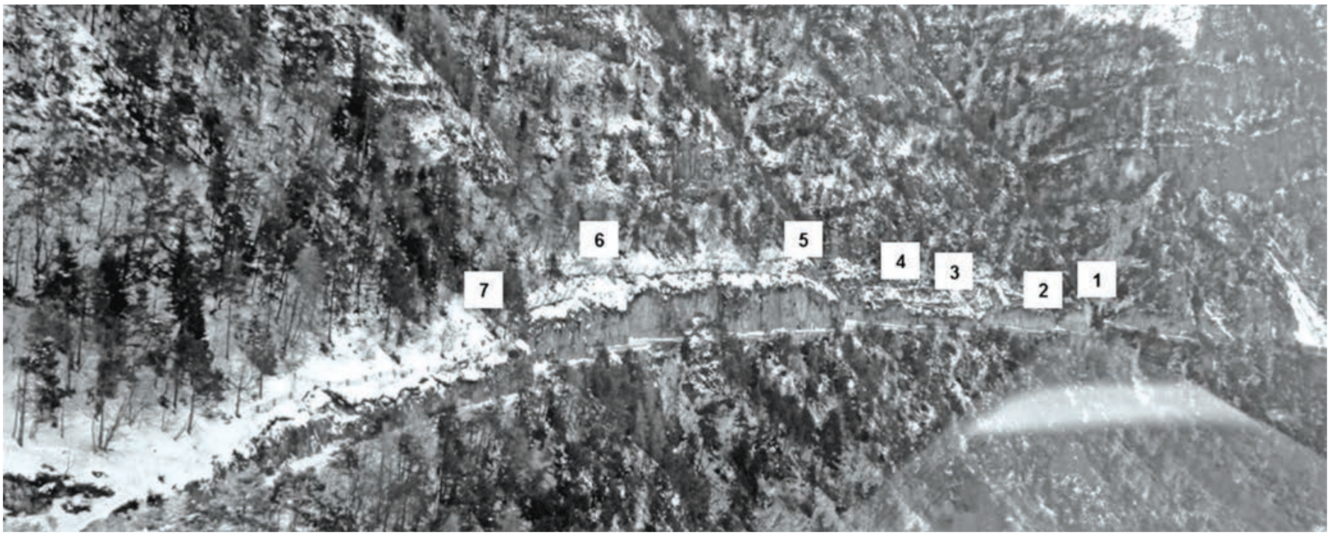

Fig. 1 – Overview of the Mendel Road with the seven impluviums where grazing avalanches occur. The Tumortal impluvium corresponds to No. 1.

Fig. 2 – Tumortal avalanche body thickness in 2014 and 2008.

vertical walls of anthropogenic origin. These walls are subject to spontaneous collapses that often subtend small rock impluviums in which small spontaneous grazing avalanches of wet snow are formed. These events are linked to a reduction in snow depth due to the rise in temperatures after snowfall. Avalanche, debris flow and rockfall phenomena occur in the Tumortal channel.

In accordance with the requirements of the Hazard Zone Planning (Decree of the President of the Province of Bolzano of October 10, 2019, No. 231), the area is located in zone H4 with very high hazard of rockfall and avalanches and is at very top of the list of intervention priorities to mitigate the hydrogeological risk on the roads managed by the Province of Bolzano (Resolution of the Provincial Council of the Province of Bolzano 842 of 8.7.2014).

2.1. Exposure to avalanche risk

As described above, multiple avalanche events, and more specifically multiple run-off channels, are observed in the study area. Due to the steepness of the rock slope and the multiple counter slopes, it is not possible to define a precise avalanche release area. Typical avalanches of the area are small-sized (max. 2500 m^3) and characterized as spontaneous and frequent avalanche types, that reach the roadway with high pressures of up to 140 kPa. They can result in the loss of human life both inside and outside the passenger compartment of cars.

Small avalanches occur every two years, while sequences of several successive avalanches due to heavy snowfall are observed every hundred years.

In 2008, the road was closed for more than two months due to heavy and persistent snowfall, resulting in the destruction of the Anas-type snow and rockfall-barrier. Later in 2011 the new 4 m high barriers were filled in, rendering the function of the rockfall barriers useless followed by a road closure of almost a month due persisting snow condition.

In 2011, the Avalanche Commission was established as a decision-making support to the Road Service. In 2014, the road closure could be limited to two weeks.

2.2. Exposure to rockfall

The slope is highly prone to rockfall, mainly in the early spring months as it is subject to winter snowmelt and freeze-thaw cycles.

The main characteristics and triggering factors of rockfall exposure can be summarized as follows:

- the presence of heavily deteriorated wooden snow barriers that are no longer effective.
- the presence of deformable and non-deformable rockfall barriers up to a maximum height of 4 m, often only 2 m and even lower. These barriers are damaged and do not guarantee coverage of the entire section.
- rock wedges larger than 4-5 m^3 can also break off from the rock steps of the slope, which, due to the intense fracturing of the rock, fragment into smaller blocks once they have reached the ground.
- on the existing barriers there are no boulder impacts with a volume greater than 0.5 m^3.

3. Design solutions for risk mitigation

Having discarded the initial design solutions of the cantilever rockfall tunnel and the retention weir in the Tumortal, an alternative design solution was implied. The strategy consists of supplementing the existing rockfall barriers with additional lines of rockfall barriers: 80 m of 6 m high barriers and 3000 Kjoule energy absorption, 60 m of 5 m high barriers and 2000 Kjoule energy absorption, and 120 m of barriers with 1000 Kjoule and of 2 m hight. In the avalanche detachment areas, wooden snow stands were placed that were easy to assemble and capable of retaining the snowpack, preventing both the detachment and further damage to the rockfall barriers.

4. Validity evaluation of mitigation measures

To assess the validity of the implemented mitigation measures, the acceptability of the residual risk on the road section was evaluated after the measures have been realized. For the assessment of acceptability, the UNI 11211-4 standard was used – In this article we exclusively illustrate the assessment of direct damage and more specifically the loss of human life. The mitigation assessment of indirect damage was conducted according to the method proposed by the Autonomous Province of Bolzano in the technical annex to council resolution 842 of 08/07/2014.

4.1. Assessment of vehicle density

Vehicle density (ρj) is defined as the number of vehicles per unit area of the investigated road. It can be deduced from the TGM (average daily traffic) and results in:

$$\rho j \text{ (vehicle/km)} = \text{TGM} / 24 / v$$

where V = average speed on the route given the very twisty nature of the track can be taken as 40 km/h

$$\rho j = 4.16 \text{ vehicle/km} = 4.16 \times 10^{-3} \text{ vehicle/m}$$

4.1.1. Vehicles affected by a rockfall event

Three types of rockfall events, that can affect the roadway, need to be distinguished: a) failure to maintain adherence nets, b) bouncing on rock and overtopping existing

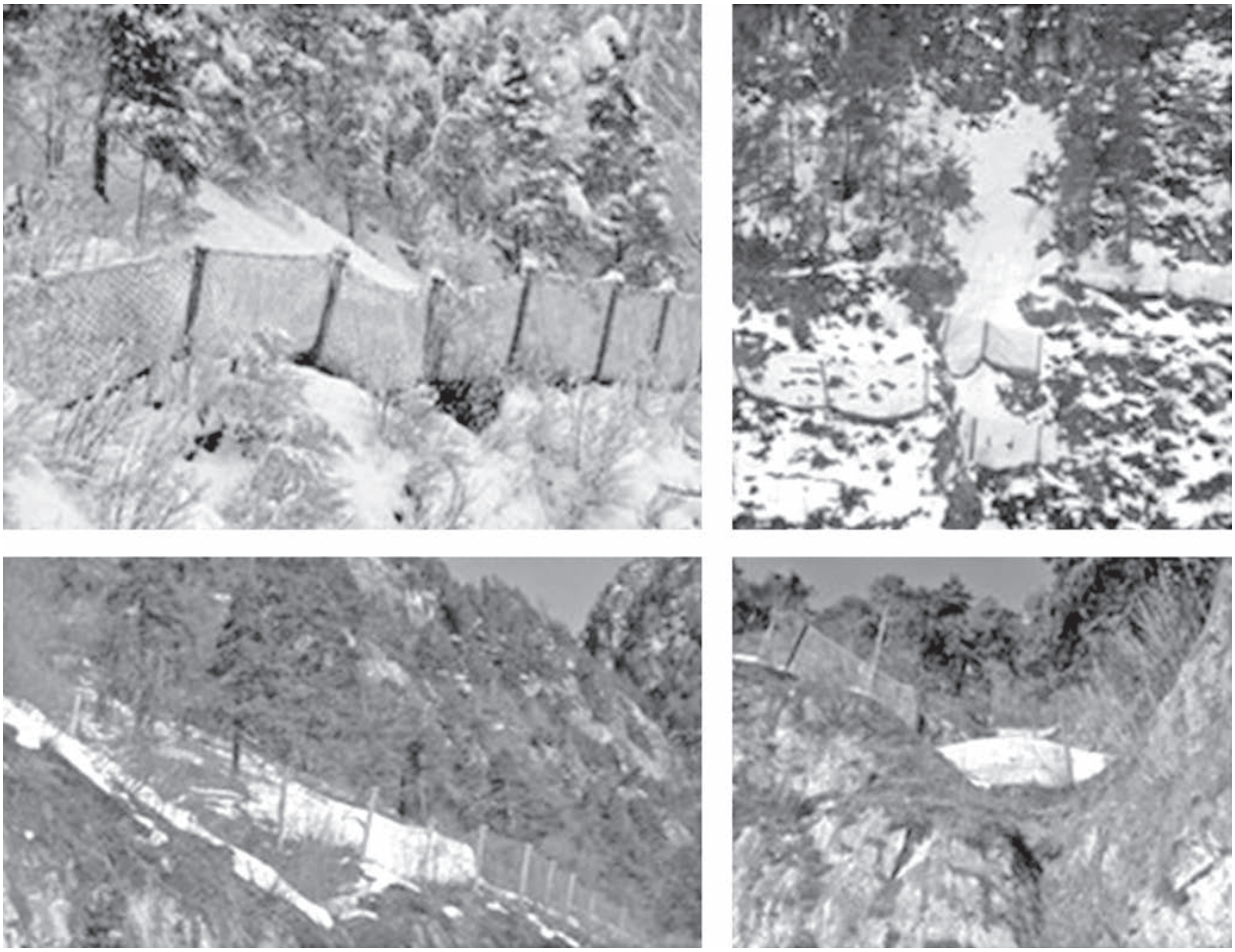

Fig. 3 – Small avalanches of wet snow along the channels obstructing the rockfall barriers; the snow often remains even after the thaw. These phenomena did not occur after the installation of the snow stands.

protective barriers, c) bouncing on snow and overtopping existing barriers.

Case (a) is mitigated by a proper inspection and maintenance plan of the operator.

If rockfall originates from a very steep rock face (case b), considerable block fragmentation is possible, as demonstrated by the fact that the blocks retained by the existing barriers are no larger than 0.5 m^3. For this reason and due to the height of the detachments, it is possible that the propagation area of a single detachment L amounts between 30 and 50 m. Fragmented blocks can simultaneously strike several points on the roadway. Using L = 40 m we also include the length of the vehicles that could only be hit in the front or rear section, causing the vehicle to swerve. The braking distance of vehicles that travel at a speed of 40 km/h amounts 12.5 m according to the recommendations of Ministerial Decree 5-11-2001. The number of vehicles affected Nv results in:

$$Nv = Pj \times L = 0.17$$

Pj = vehicle density
L = length of invested section.

The number of invested users per event (N_U):

$$N_U = n \times Nv = 0.25$$

n = average number of users per means of transport on the route conservatively assumed 1.5 (average in the Autonomous Province of Bolzano is 1.2)

4.1.2. Loss of life estimation in rockfall risk assessment

While considering an acceptable risk of less than 10-4/10-5 deaths per year in case of natural hazard events, data on the probability of loss of life are reported on the F/N diagram proposed by UNI 11211-2.

We therefore cautiously assume the number of affected users and potential fatalities per event, respectively, to be 1

The number of annual fatalities is estimated by

$$Nf = N_v / (Tr)$$

Nv = number of fatalities on an annual basis
Tr = return time

It is assumed that the existing barriers influence the frequency of a rockfall event as follows: (i) 500 m of roadway is approximately hit every 1.5 years (Road Service and Geological Service intervention data) and, (ii) 40 m of roadway is hit every 18.5 years. After the installation of new barriers has been terminated this frequency is reduced by 95% (UNI 11211-3 standards)

The Nf value in the initial situation result amounts

$$Nf = 0.25 / 18.5 = 1.3 \times 10^{-2}$$

After the installation of the new barriers Nf resulted in

$$Nf = 1.4 \times 10^{-4}$$

All these values must be regarded as precautionary, as the probability of car blockage or braking will result in death is small compared to other damages such as injuries or damage to the car.

In the F/N graph below, the risk levels before and after the mitigation measures are illustrated:

4.2.1. Vehicles involved in an avalanche event

Considering an avalanche route length of 80 m, as well as the sum

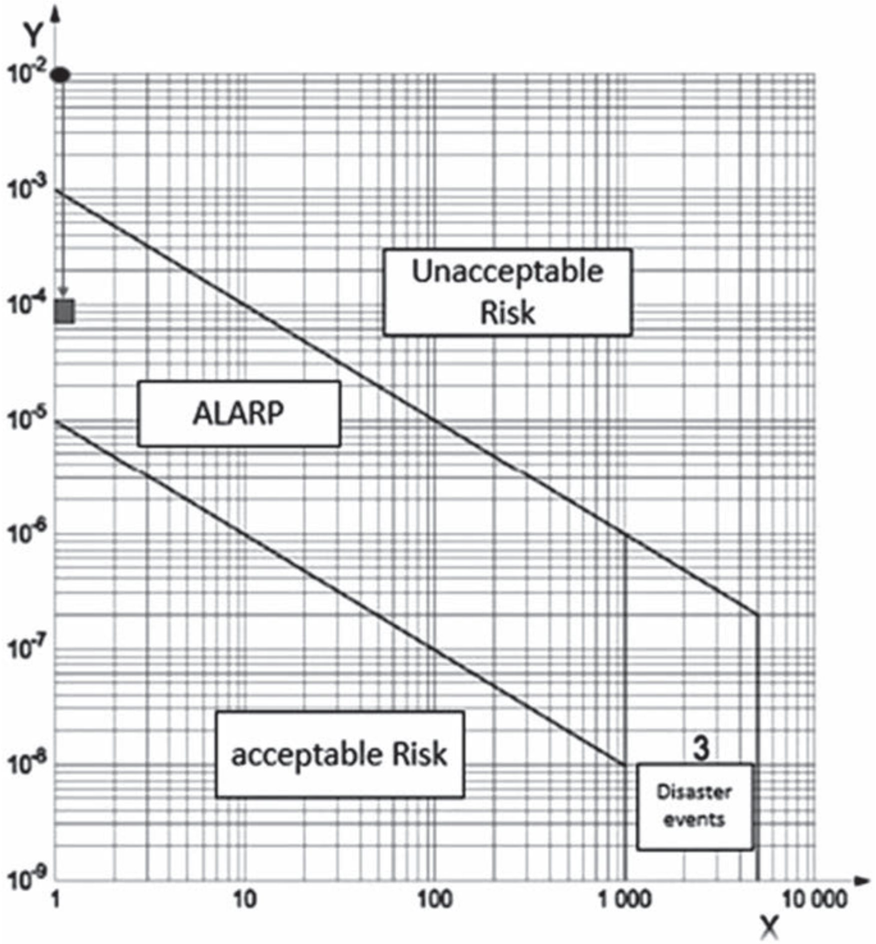

Fig. 4 – Effect of rockfall barrier mitigation on the F/N diagram; (ALARP = *As Low As Reasonably Practicable).*

of the length of the vehicle hit and the braking distance of 18.5 m, a route L = 100 m can be assumed in excess. The number of vehicles involved amounts:

$$Nv = Pj \times L = 0.33$$

And the number of users involved are calculated by:

$$N_U = n \times Nv = 0.5$$

4.2.2. Assessing the risk of loss of life in the case of avalanche events

According to the findings of the avalanche commission on the Tumortal avalanche, the following return times can be deduced: (i) the return time for a single release amounts two years, while (ii) the return time of two releases within a short timespan – excluding the possibility of thawing – is approximately four to five years. The 6 m high multi-risk barrier is capable of blocking two medium-sized avalanche detachments, but not to block a higher number of detachments. The probability of three or more avalanche detachments based on the snow data is around 100 years.

Therefore, the number of fatalities before the implementation of the multi-risk barrier are calculated by

$$Nf= 1.33 / 2 = 6.5 \times 10^{-1}$$

The number of fatalities with the multi-risk barrier capable of containing two successive events is

$$Nf= 6.5 \times 10^{-1}/100 = 6.5 \times 10^{-3}$$

Thus, with the configuration of protective structures presented and discussed, it is possible to achieve a situation just above the ALARP (As Low As Reasonably Practicable) threshold. In this case, the Avalanche Commission's intervention is decisive to mitigate the risk until further structural measures are implemented, such as the construction of a bridge that would eliminate the avalanche hazard on the road segment.

Since avalanche events are directly triggered by precipitation and adverse snowpack conditions, they are more predictable than rockfall events. Therefore, diligent monitoring by the avalanche commission is considered a valid risk management strategy that can reduce the risk to an acceptable level.

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