Reevaluation of Design Loads for an Existing Avalanche Protection Gallery

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Introduction

- The verification of existing structures with current structural design codes is often difficult.
- The cost of retrofitting can be significant.

⇒ Are the required investments proportionate?
⇒ Is it possible to accept a lower reliability level?

The decision should be made based on risk and efficiency considerations!
Application to an existing avalanche gallery

- Located in the Swiss Alps (GR)
- Built in the 1960’s, 2km long
- Many avalanches, no damages
- Reassessment with new design loads based on ASTRA 12007
- Very high retrofitting costs!

Map: swisstopo
Source: TBA Graubünden
Risk-based design based on SIA 269 / JCSS PMC

<table>
<thead>
<tr>
<th>Efficiency of safety measure $E = \Delta R/C_s$</th>
<th>Failure consequences $\rho = C_F/C_B$</th>
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</table>
| Efficiency                                      | Minor: $\rho < 2$ | Moderate: $2 < \rho < 5$ | Large: $5 < \rho < 10$
| Small: $E < 0.5$                               | $\beta_t = 3.1$  | $\beta_t = 3.3$  | $\beta_t = 3.7$
|                                               | $P_f \approx 10^{-3}$ | $P_f \approx 5 \cdot 10^{-4}$ | $P_f \approx 10^{-4}$
| Normal: $0.5 \leq E \leq 2.0$                 | $\beta_t = 3.7$  | $\beta_t = 4.2$  | $\beta_t = 4.4$
|                                               | $P_f \approx 10^{-4}$ | $P_f \approx 10^{-5}$ | $P_f \approx 5 \cdot 10^{-6}$
| Large: $E > 2.0$                               | $\beta_t = 4.2$  | $\beta_t = 4.4$  | $\beta_t = 4.7$
|                                               | $P_f \approx 10^{-5}$ | $P_f \approx 5 \cdot 10^{-6}$ | $P_f \approx 10^{-6}$

👋 Annual target reliabilities based on optimisation

Gallery example

- Minor consequences of failure
- Small efficiency of safety measure
Deriving design values from the target reliability

General formula:

\[ X_d = F_X^{-1} \left( \Phi \left( \alpha_X \beta_t \right) \right) \]

Distribution of \( X \)  FORM sensitivity

⇒ Required: Probabilistic model for the random variable \( X \)

⇒ Difficult for avalanche loads: Expert judgement is often the only information available

Source: TBA Graubünden
Probabilistic modelling of avalanche loads

Standard approach: Expert estimates for scenarios with predefined return periods

⇒ Exceedance probability [1/a]:
\[
P\left( X > x_{T_i} \right) = 1/T_i
\]

⇒ “Fit” probability distribution to several scenarios
Probabilistic modelling of avalanche loads

Standard approach: Expert estimates for scenarios with predefined return periods

⇒ Exceedance probability \([1/a]\):
\[
P\left(X > x_{T_i}\right) = 1/T_i
\]

⇒ “Fit” probability distribution to several scenarios

⇒ Quantify the uncertainty of the scenario estimates
Results for the avalanche protection gallery

- The new design loads were used for a structural reassessment.

- Assessment for $\beta_t = 3.1$ (low efficiency of safety measure) to decide which parts of the gallery have to be retrofitted.

  ⇒ Only around 30% of the 2km gallery have to be strengthened.

- Design values for $\beta_t = 4.2$ (high efficiency of safety measure) for the planning of retrofitting works.

  ⇒ The retrofitting works are planned with higher design loads than those derived from a standard, deterministic assessment.

  ⇒ More efficient resource allocation than in standard approach.
Conclusions

• The target reliabilities presented in SIA 269 / JCSS PMC allow to consider cost efficiency in a standard deterministic design.

• The approach requires probabilistic models for the considered load / resistance variables.

• Loads due to natural hazards (e.g. avalanches) can be modelled based on expert estimates for several scenarios.

• The application to existing structures leads to a more targeted investment of limited resources.
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