Optimizing monitoring: application to assessment of roof snow load

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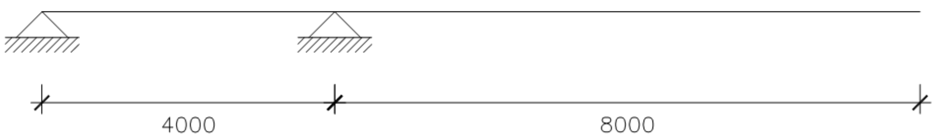
Diamantidis, Sykora, Lenzi. ***Optimizing Monitoring: Standards, Reliability Basis and Application to Assessment of Roof Snow Load Risks (in press)****; In: SEI - Journal of IABSE*

Diamantidis, Sykora. ***Optimizing monitoring – implementation of draft guideline and case study of roof exposed to snow loads****. IABSE Symposium 2018, Nantes*

3. ASSET INFORMATION

- Stadium constructed in the beginning of 1990s
- Located in Northern Italy, altitude - 190 m
- Capacity: 4000 spectators - CC3 structure
- Structural system:
  - member: cantilever steel beam IPE450
  - system: spacing between adjacent beams - 5 m with stiffening members
- Design requirements:
  - snow loads: old code D.M. 12.02: 0.9 kN/m^2, EC1-3: 1.25 kN/m^2
  - design requirements: ***resistance of the roof is about 90% of that required by the Eurocodes (in terms of design values)***



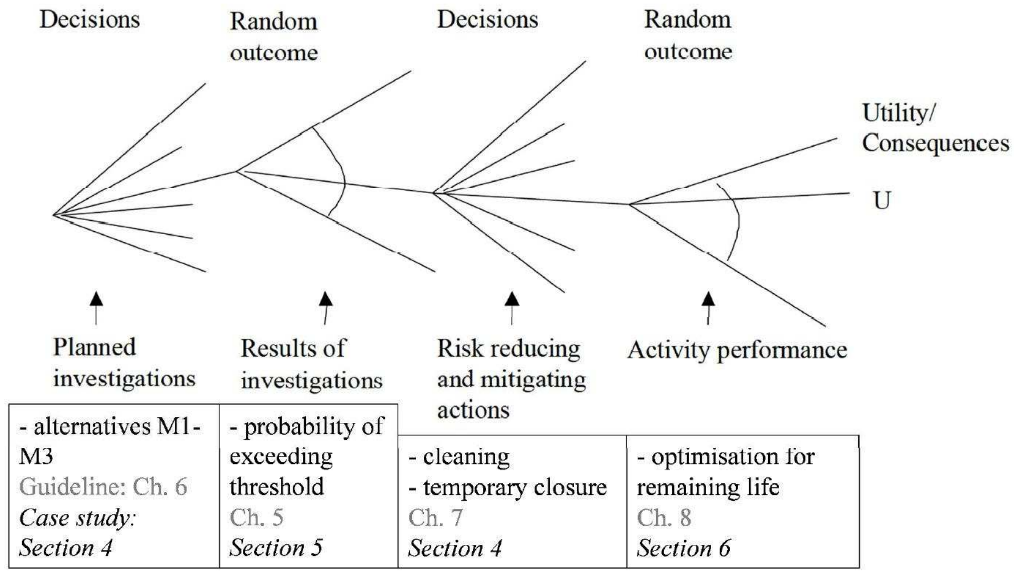
4. STRUCTURAL PERFORMANCE (reliability analyses)

a) prior information (uncertainties based on JCSS PMC)

- β_{comp} **= 3.85 < 5.2** given in EN 1990 for CC3 (annual values)
- β_{sys} = 3.55 (lower bound estimate as horizontal stiffening members and other secondary beams will likely provide some redundancy)

b) updating (survival of a high load equal to 1.35kN/m^2) - *no significant improvement*

DECISION TREE FOR PRE-POSTERIOR ANALYSIS



Failure consequences – ECONOMIC LOSS

- Building structural cost C_{str} – cost of replacing whole structure including secondary members and equipment

- Economic loss:
  - repair/ replacement: structural cost of whole roof $0.2\text{-}0.3C_{str}$
  - local damage of 10-25% roof area

  $\rightarrow 0.02\text{-}0.075C_{str}$

  - business losses due to structural malfunctioning – repair time six months $\rightarrow 0.1\text{-}0.5C_{str}$

$\rightarrow$ **$C_{econ} \approx 0.12\text{-}0.58C_{str}$**

Failure consequences - HUMAN LOSSES guidance missing

Situation 1 (three hours per two weeks in a winter season, 9‰ of time):

- Stadium occupied, in a winter season about 2 000 spectators with ***200-500 persons under collapsed area***

  Assumption: utilisation of stands - negligible effect on likelihood of roof collapse
- ***Conditional probability*** of casualty given the structural failure 1-5% (little experience with stadia)

$\rightarrow$ number of fatalities $N_f \approx <200, 500> \times <0.01, 0.05> = <2, 25>$

Situation 2: technical staff, coaches and rarely sportsmen – ***1-10 persons*** $\rightarrow N_f \approx <1, 10> \times <0.01, 0.05> = <0.01, 0.5>$.

$\rightarrow N_f \approx <2, 25> \times 0.009 + <0.01, 0.5> \times (1\text{-}0.009) = <0.03, 0.7>$

- SVSL ≈ 2000 k€ for Italy for fatalities, doubled to account for injuries $\rightarrow C_{human} \approx <0.03, 0.7> \times 2 \times 2000$ k€ = 120-2 800 k€ $\rightarrow 0.004\text{-}0.093C_{str}$
- **Total failure consequences of partial roof collapse $0.12\text{-}0.67C_{str}$**

7. DECISION ANALYSIS threshold values

Guidance missing

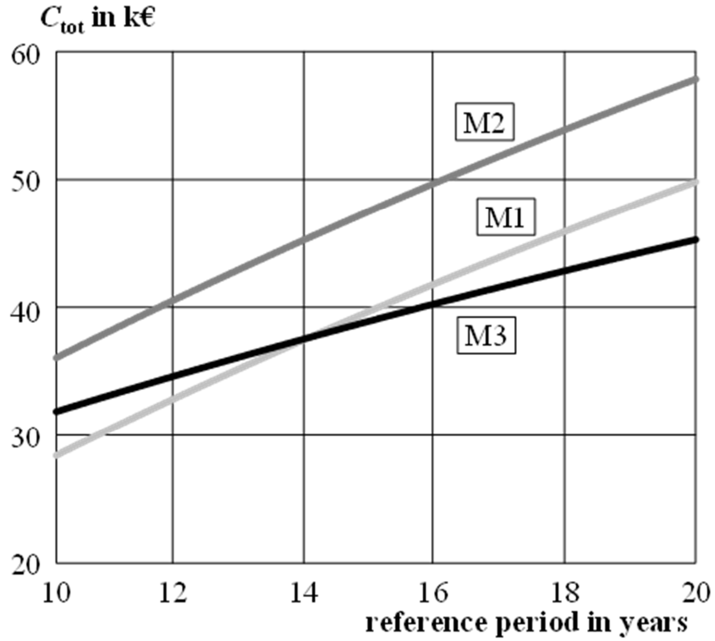
Table 3. Thresholds for observed variables and related return periods

Monitoring	β_{opt} = 3.7 (exceed. threshold)			Partial factors			Bounded distr., annual β_1 = 5.2		
	Threshold	S[1)]	T[1)]	Threshold	S	T	Threshold	S	T
M1 – ground snow load	1.40 kN/m^2	≈ 0.8 × 1.40 = 1.12	49	1.29 kN/m^2	1.03	32	0.91 kN/m^2	0.73	7
M2 – roof snow depth in m	0.38 m	1.08[2)]	38	0.37 m	1.04	33	0.28 m	0.75	8
M3 – roof snow load in kN/m^2	1.21 kN/m^2		75	1.03 kN/m^2		31	0.76 kN/m^2		9

[1)]S = corresponding roof snow load in kN/m^2; T = return period in years. [2)]Corresponding roof snow load is (1.09 × 0.38 + 2.4) × 0.38 = 1.08 kN/m^2.

7. LIFECYCLE COSTS

representative results for M1, M2, M3 based on acquisition and operation costs



8. CONCLUSIONS

1. The ***required information*** by SHM needs to be clearly specified before the monitoring system is installed.
2. ***Design of SHM*** is a complex issue including:
    a) Component and/ or system structural reliability
    b) Identification of possible monitoring strategies
    c) Specification of threshold values for observed variables
    d) Selection of monitoring strategy based on total cost optimisation.
3. SHM systems allow for a ***real time evaluation*** and support decisions regarding safety measures
4. Case study is compatible with draft guideline and illustrates clearly the application of key principles.
5. Snow-dominated structures:

- Probabilistic analysis and monitoring helps to better understand and control the associated risks (return period for up to 75 years)
- Feasibility analysis of safety measures (early warning)
- Cost-benefit analysis to establish case-specific thresholds (partial factors conservative here)
- Human losses due to failure in a winter season low (**<1 / 4000!**)