

On the Acceptable Risk for Structures Subjected to Geohazards

Dimitris Diamantidis¹, **Sebnem Düzgün**²,
Farrokh Nadim³, Martin Wöhrle⁴

^{1,4} University Of Applied Sciences, Regensburg Germany

² Middle East Technical University, Ankara Turkey

³ International Centre for Geohazards, Oslo Norway



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OUTLINE

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Introduction

Risk acceptance can be defined by two different methods:

Implicit ⇒ Safety equivalence with other industrial sectors (e.g. stating that a certain activity must impose risk levels at most equivalent to those imposed by another similar activity)

Explicit ⇒ Provide either a quantitative decision tool to the regulator or a comparable requirement for the industry when dealing with the certification / approval of a particular structure or system.



Factors of Risk Acceptability

The nature of risk determines its acceptability which is associated with (Osei et al., 1997):

- ▶ Voluntary vs. involuntary
- ▶ Controllability vs. uncontrollability
- ▶ Familiarity vs. unfamiliarity
- ▶ Short/long-term consequences
- ▶ Presence of existing alternatives
- ▶ Type and nature of consequences
- ▶ Derived benefits
- ▶ Presentation in the media
- ▶ Information availability
- ▶ Personal involvement
- ▶ Memory of consequences
- ▶ Degree of trust in regulatory bodies.



Human Safety

- ▶ **Individual Risk:** Annual probability of being harmed due to a hazardous situation.
- ▶ **Societal Risk:** The risk of widespread or large scale detriment from the realisation of a defined risk, the implication being that the consequence would be on such a scale as to provoke a socio/political response.



Suggested Individual Risk Levels for Landslides

Slopes	Individual risk (loss of life/yr)	Reference
Natural slopes	10^{-3}	
Existing engineered slopes	$10^{-4} - 10^{-6}$	Fell & Hartford (1997) AGS (2000)
New engineered slopes	$10^{-5} - 10^{-6}$	
Existing	10^{-4}	
New	10^{-5}	ERM-Hong Kong (1998)



Societal Risk and F - N Curves

Societal risk reflects the society's point of view. In this perspective, risks having low hazard and high consequence are taken into account. For individual and societal risk, the unit of risk is the loss of life/yr. Societal risk is generally expressed by f-N or F-N curves.

When the frequency of events which causes at least N fatalities is plotted against the number N on log log scales, the result is called F-N curves (Bedford, 2004). If the frequency scale is replaced by annual probability, then the resultant curve is called f-N curve.

$$\log f = a + b \log N$$



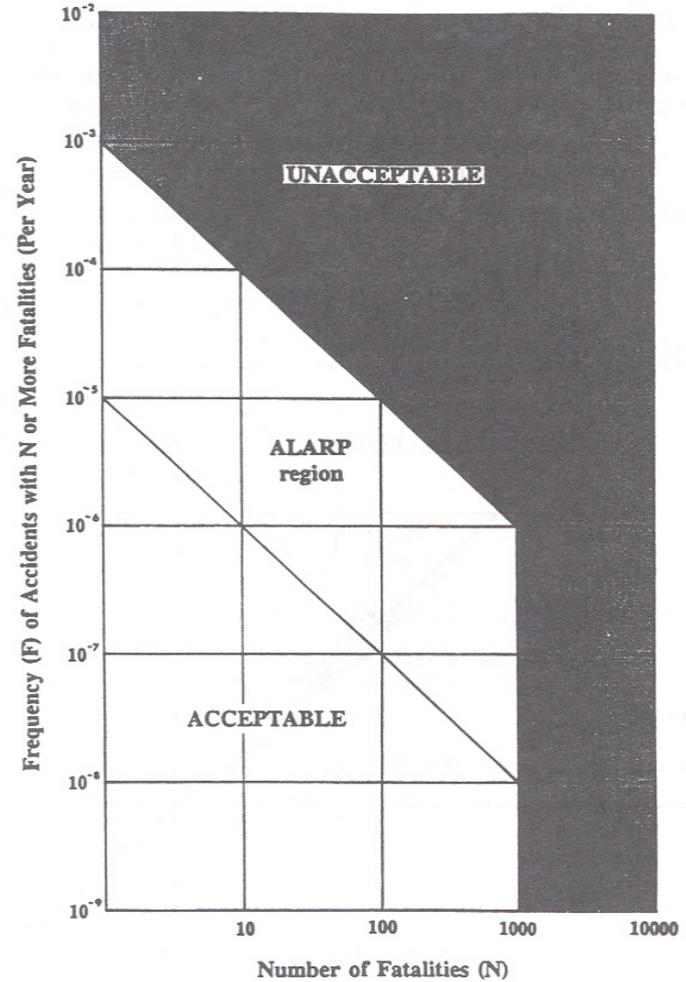
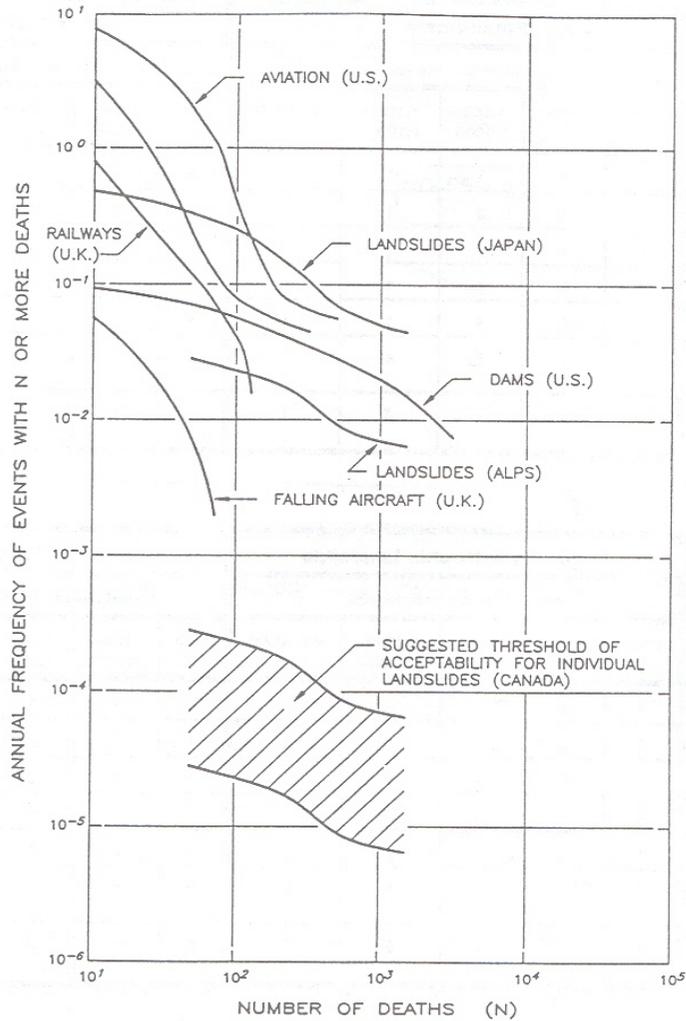
Properties of F - N Curves

1. F-N curves are constructed based on historical data in the form of number of landslides and related fatalities.
2. They in fact represent current situation i.e. the situation we live now.
3. F-N curves form the basis of developing societal acceptability and tolerability levels.
4. The F-N curves can be constructed for various geographical units such as country, province, state etc.
5. The number of landslides and related fatalities within the considered geographical unit determine the acceptability and tolerability criteria.



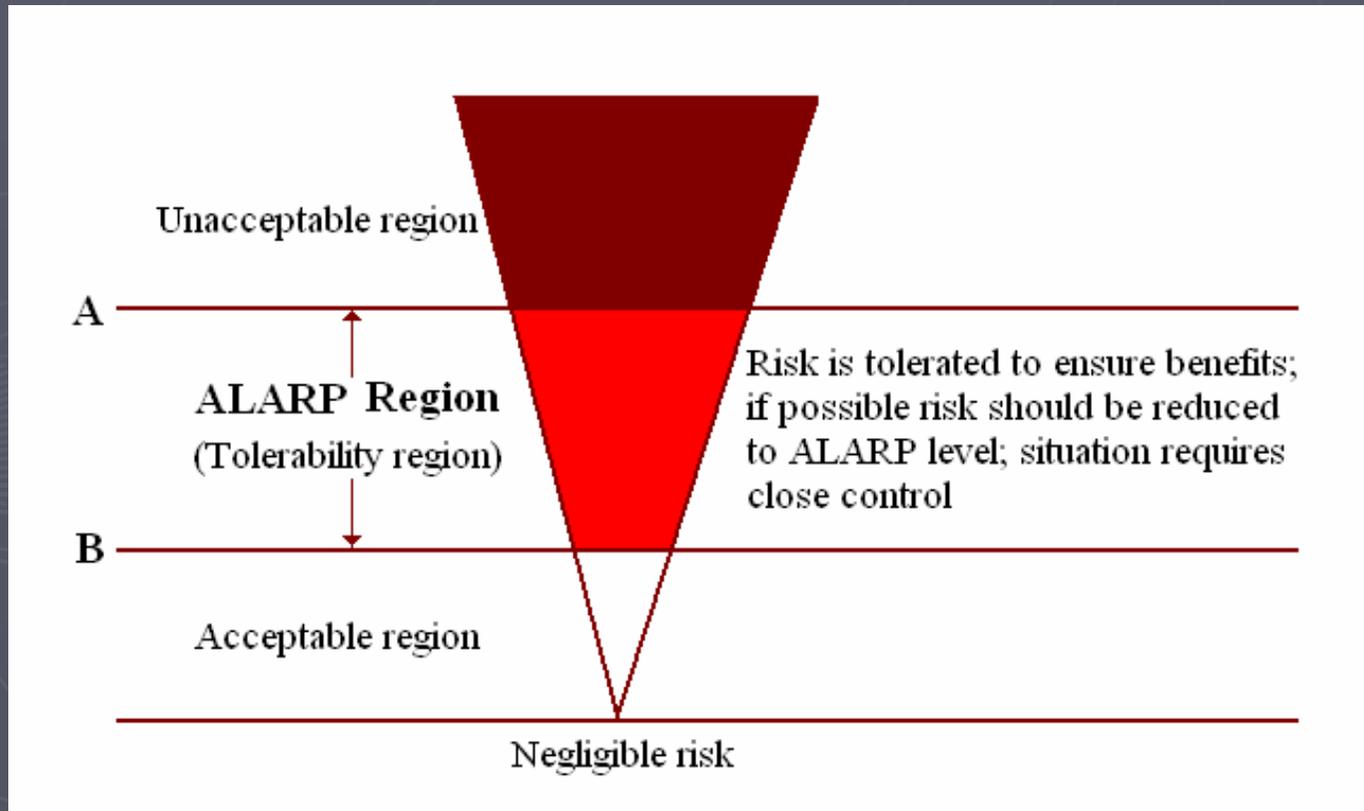
f-N Curve for various natural and man-made disasters (Morgan, 1991)

Hong Kong Government Planning Department's Societal Risk Criteria for potentially hazardous installations (1994)



Principles of Acceptable\Tolerable Risk Establishment

Acceptable risk refers to the level of risk which requires no further reduction. Tolerable risk refers to the risk level assessment in exchange for certain benefits. It is the society's decision whether to accept or tolerate the risk.



Direct Cost Benefit Analysis

The problem of identifying an acceptable level of risk can also be formulated as an economic decision problem.

The optimal level of safety corresponds to the point of minimal cost.

The optimisation problem can be solved using the Life Quality Index (LQI) approach (Rackwitz, 2002).



Life Quality Index

The strategy is based on a social indicator that describes the quality of life as a function of:

g: the gross domestic product per person per year

e: the life expectancy at birth

w: the proportion of life spent in economic activity.

$$L = g^w e^{(1-w)}$$



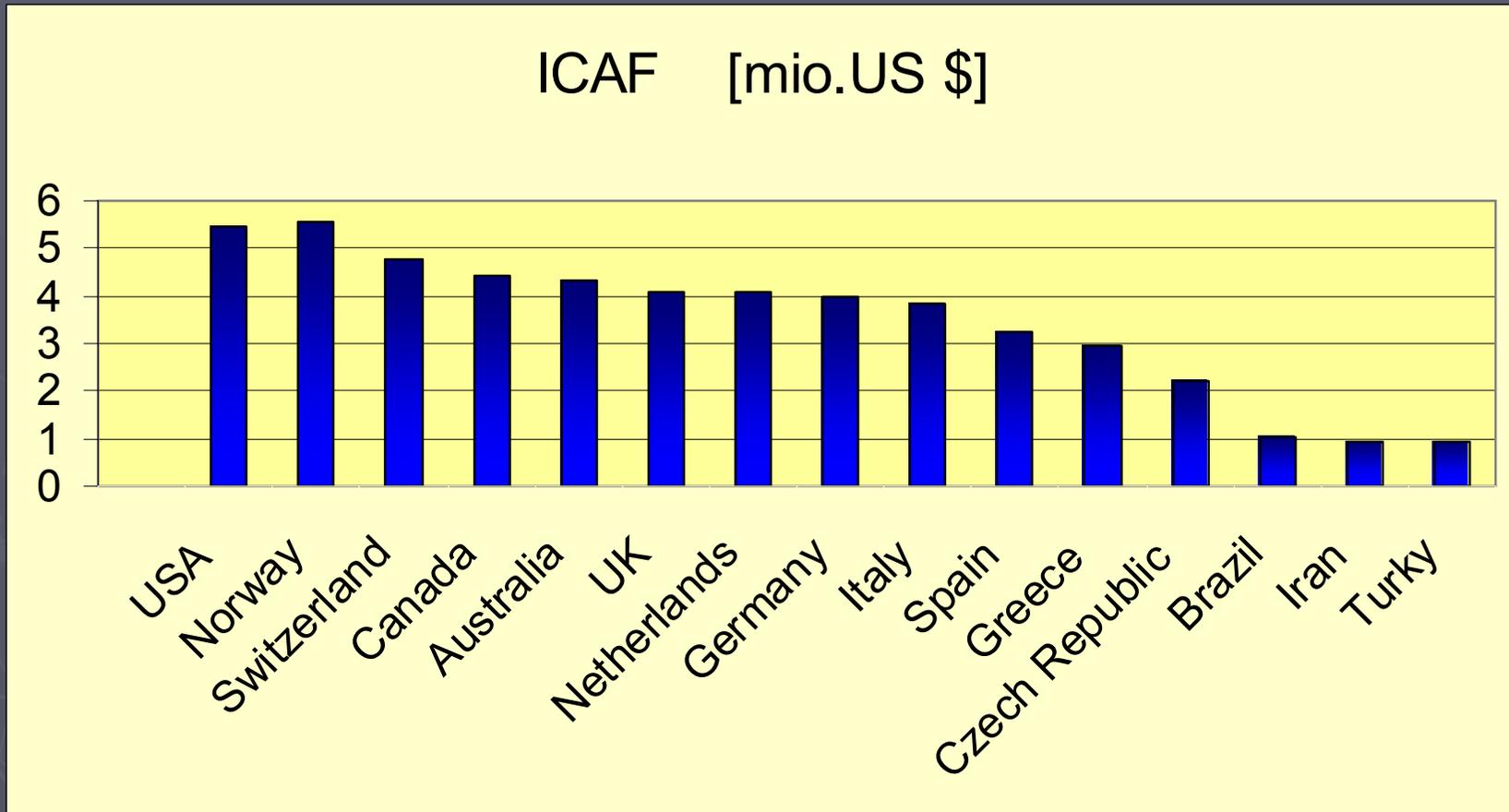
Implied Cost of Averting a Fatality (ICAF)

It is not the value of one's life or the amount of a possible monetary compensation for the relatives of victims but monetary value, which society willing to invest for saving one's life

$$\text{ICAF} = g e (1-w) / (4w)$$



ICAF values for various countries



By applying the safety vs. cost-benefit approach risk acceptability criteria are indirectly applied by evaluating each investment into safety. For each possible safety measure k the following parameters are therefore considered:

- ▶ Investment costs (C_{Ik})
- ▶ Annual maintenance/operation costs (C_{Ak})
- ▶ Desired lifetime of measure (T)
- ▶ Risk reduction due to measure k divided into dR_k
 - reduction related to human risk dR_{Hk}
 - reduction related to economic risk dR_{Ck}

In addition if we consider a discount rate $\delta(t)$ the evaluation of each individual safety measure can be made on the basis of the aforementioned assumptions related to risk acceptability, cost functions and risk reduction by the following inequality:

$$(C_{Ik} \times \delta(T))/T + C_{Ak} < ICAF \times dR_{Hk} + dR_{Ck}$$

If the inequality is satisfied then the safety measure is beneficial. However it is mentioned that the parameters entering (4) are associated to significant variabilities and therefore sensitivity analyses are necessary in order to analyse the results.



Towards Codified Criteria

In terms of reliability based approach the structural risk acceptance criteria correspond to a required minimum reliability herein defined as target reliability.



Target Reliability Indices

Cost of safety measure	Consequences		
	Minor	Moderate	Large
Large (A)	$\beta=3.1$ ($p_F \approx 10^{-3}$)	$\beta=3.3$ ($p_F \approx 5 \times 10^{-4}$)	$\beta=3.7$ ($p_F \approx 10^{-4}$)
Normal (B)	$\beta=3.7$ ($p_F \approx 10^{-4}$)	$\beta=4.2$ ($p_F \approx 10^{-5}$)	$\beta=4.4$ ($p_F \approx 5 \times 10^{-6}$)
Small (C)	$\beta=4.2$ ($p_F \approx 10^{-5}$)	$\beta=4.4$ ($p_F \approx 5 \times 10^{-5}$)	$\beta=4.7$ ($p_F \approx 10^{-6}$)



Target Reliabilities for Earthquakes

The frequently used design return period for verification purposes can be easily obtained based on first-order reliability considerations from:

$$T = -1 / \ln (1 - \Phi(-\alpha\beta))$$

T : Return period for design purposes

$\Phi()$: Standard normal integral

α : Sensitivity factor of earthquake hazard

β : Target reliability index



Target Reliabilities for Landslides

- ▶ Establishment of target reliability indexes for the structures in rapid landslide situations, requires first the prediction of landslide run out area boundary and potential energy impact produced by the slide to the structures within the boundary of the run out area.
- ▶ For creeping type of landslides, the position of the structure with respect to slide and the rate of movement should be taken into account.
- ▶ Furthermore, in landslide case, the construction of slopes or safety assessment of existing natural and manmade slopes are of primary concern.



Target Reliabilities for Slopes

Dam Design	$\beta=3.1$ ($p_F \approx 10^{-3}$)	Christian et al (1994)
Rock Slope	$\beta=2.3 - 3.1$ ($p_F \approx 10^{-2} - 10^{-3}$)	Genske and Walz (1991)
Mine Slope	$\beta=1.88$	Düzgün et al. (2003)



Concluding Remarks

- ▶ The nature of geohazard affect the method of risk acceptance. For geohazards like earthquakes, in which the magnitude of hazard can be determined, risk acceptance criteria are more mature than geohazards like landslides, in which it is extremely difficult to express the hazard magnitude.
- ▶ Risk acceptance criteria are based on optimisation (costs versus safety improvement); a safety class differentiation can be thereby considered.
- ▶ In order to satisfy modern risk acceptance criteria for earthquakes three components of earthquake performance objectives are needed: probabilistic ground motion level definition, structural performance level, target reliability of achieving a performance level.
- ▶ Assessing target reliability levels in case of landslide requires, prediction of landslide run out area and position of structure with respect to runout area. Moreover, target reliability levels should be established for slopes of various kinds based on comprehensive calibration studies.

