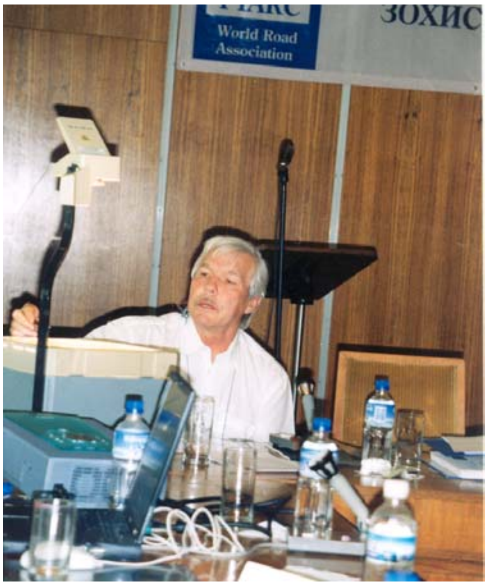

Effect of Frost on the Roads of Swiss Alps

(Extended Abstract)

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1. General motivation

Although Switzerland is situated in a temperate climatic zone, it has local analogies with countries of Central Asia. Cold temperature is no more due to continental effects but the altitude. Alpine regions are strongly affected by frost action, mainly above 2000 m. Is it useful to study these high territories as the main road infrastructures are much below this level? Of course, for several reasons :

a) Many roads reach high altitudes (alpine passes, connecting roads for tourist stations)

b) Although the problems of foundations on embankments are generally well solved, the road remains vulnerable due to slope movements, which often occur at a higher level than the road itself

c) Climatic change needs to reconsider the geological hazard assessment in the perspective of sustainable development.

2. How is frost distributed now in the Alps ?

A general typology determines four cases :
- Regions with or without permafrost
- Frost in debris or in rocks

Typical examples are illustrated during the conference : rock glaciers, ice in rock fissures.

3. Control of the equilibrium of frozen terrains

The thermal evolution of frost in underground is determined by the thermal balance. Two situations should be considered.

Static state : pure conductive model without convection

Dynamic state : heat fluxes by matter transport (liquid, gas, solid) => Importance of discontinuities in the medium

Origin of discontinuities in frozen terrains. Three main causes :
- Fluid convection (geothermal anomalies or groundwater and air circulation)
- Mechanical failures (rock glaciers)

Groundwater paths kept open due to heat convection through water and air convection.
Solidification of water brings important heat flow to be dissipated in the medium. => High thermal inertia.

4. Global change scenarios in mountainous areas

The general scenarios at the Earth scale will not be discussed here. Now, an anthropogenic warming period (increase of temperature between 1 and 5 degrees in 50 years) is generally accepted.

These conditions cannot be transposed directly to mountainous regions due to some very particular factors :
- relief (importance of radiation balance, 3D processes)
- microclimates
- important role of solid-state water (low thermal conductivity of snow, high albedo, latent heat of fusion)
- snow transport by wind
- thermal buffering due to glaciers

These difficulties explain why there are still important uncertainties. One main question is for example the effect of temperature increase on precipitations (particularly the snow). We know that the time of the snowfall, the duration of the snow cover influence directly frost progression in the soil.

Despite these uncertainties, it is very probable that the frost in underground will be dramatically reduced.

5. Climatic warming simulation

Base principle

Global temperature increase = Zero degree line higher in mountains = partial or total melting of permafrost, melting of a number of small and medium-size glaciers.

6. Impact on water resources

Reduction of frost in soil and underground => increase of the recharge of deep aquifers => greater water resources.
But : thermal inertia is reduced => hydrogeological inertia is also reduced => difficulty in the dry winter season.

Modifications on river regime : peak discharge of spring will be lower (more infiltration, less runoff).

7. Impact on slope stability

The following impact can be expected, for debris and rocks in general and on for the mountainous roads in particular.

Frozen soils

Frozen cover weaker
Higher groundwater levels
Higher hydrostatic pressure
Higher stress on the frozen shield
Lower friction between solid elements
Trend to liquefaction of greater masses
Risk of failure of the shield and mud flows

Frozen rocks

Ice wedges deeper
Instability of greater rock masses

For road slope stability, the trend is a reduction of small-scale mudflow events. On the contrary, deeper landslides should become more probable. Rock fall should be less continuous but more catastrophic. This last point is reinforced by the evolution towards more frequent extreme rainfalls.

8. Task for scientists

The following axes should be developed in the field of research :

Relationship snowmelt – soil melt – groundwater recharge in mountainous areas (field experiments, 2D modelling)

Better knowledge of the space - time distribution of ice bodies in the field

Study of the renewal of ice in permafrost, especially advective heat fluxes (tracing tests, isotopes, hydrochemistry)

Development of finite elements codes taking into account thermal and hydraulical coupling in order to test several scenarios.

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