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# 3D modelisation of snow slabs stability

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**abstract :**

**Snow slabs stability is a real problem to study in a mecanical point of view. A non exhaustive review of the different factors used to evaluate this stability or instability is done. All of them have been done in two dimensional cases, for an infinite constante slope and constant thickness of the snow cover. They are obtained by dividing a stress due to the snow pack weight by a snow hability. We present a numerical way for estimating the mecanical stability on any three dimensionnal slope. The mechanical stability factor is calculate with a stress strain 3D code using an elastoplastic behavior law for the snow. It considers a criteria of failure either in tension or in elasto-plasticity (Mohr Coulomb law) depending of the snow layer which fails. The application shown is a classic slab case and we are able to draw by the numerical calculation maps of a stability index in each layer, reproduces the phenomena generally observed in this case.**

## 1 INTRODUCTION

The transition from snow slabs stability to instablity was studied since many time, but seems to be not completly satisfying. In the Alps those avalanches are dangerous because they are usely triggered by skiers themselves just near ski resorts . They often seem to be aleatory triggered as there are no general rules who managed them. Others types of avalanches, even if they cause a lot of materials damages, seem to be less impressive for peoples but for insfrastructures.

Since more than 30 years many researches have tried to held an index to know or forecast weather a slab is instable, probablely instable or not instable. All of those indicators have the same disadventages : they were established for very simple cases espacially two dimensional geometry and a only shear rupture type of the stability (figure 1). By adapting those indexes to a shear or tension rupture type (depending of the case) and computing it in a three dimensional strain stress code we become able to draw maps of a local stability index in an entire slope, and for each layer. With such a tool we become able to understand mecanisms of triggering of slabs avalanches, and in the future the forecast will be better.

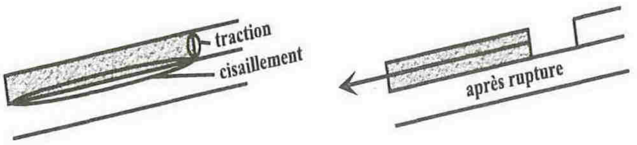



*figure 1 : triggering of a slab avalanche*

## 2 SNOW INDEX STABILITY

Since snow stability was studied many different indexes were used, some of them being an increase of the precision of the first ones. Their major caracteristics were the simplicity of their theoretical bases :

All refer to a 2 D geometry and an average calculation. They are based on a shear type rupture only, and the layered geometry in an infinite layer homogeneous, with a constant caracteristics (slope, depth, weight....)

The simpliest one recenced by JAMIESON [JAM 93] is homogeneous more to a solid friction coefficient and has been used to forecast the opportunity of avalanches triggering on canadian's motorways .

$$SF = \frac{\tau_{rupt}}{\sigma_v} \text{, avec : } \sigma_v = \sum \rho_i . g . e_i$$

It is the shear resistance of the snow (experimentaly measured) divided by the gravity stress of the layers over the potential shear rupture. It was supposed to be instable when the coefficient is more than the tangente of the real slope angle.

Another factor, S, which seems more accurate in a mecanical strengh point of view, is the ratio of the shear strengh to the shear stress state in the slab [CON 84].

the shear stress state $\tau$ is calcultated by :

$$\begin{cases} \sigma_n = \sigma_v . \cos(\alpha) \\ \tau = \sigma_v . \sin(\alpha) \end{cases} \text{, avec : } \sigma_v = \sum_i \frac{\rho_i . g . e_i}{\cos(\alpha)}$$

(see figure 2 for the convention used)

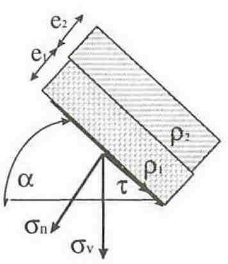



*figure 2 : calculus convention*

And the shear admissible stress can either be measured in the lab or in situ (ruchtblock method) or be calculate assuming a mohr coulomb law behavior for the snow.

The last hypothesis leads to :

$$S = \frac{\tau_{rupt}}{\tau} = \frac{C + tg(\Phi).\sigma_n}{\tau}$$

in where the tg ϕ can be calculated using Roch experimental laws: $tg\Phi = 0.08C + 0.4$ for fine grains snow type or any other one forother snow types [ROC 66] .
The two precedents indicators were compared and it demonstrates that : it just translates the range of the value of the probable stability, that is to says that instables slabs were caracterised in both cases by using an accurate critical value [JAM 93].
Some modifications were made by taking into account the increase of stresses due to a skier or a walker or even a ratrack [FÖH 87]. And a correction scale factor has been proposed to take into account the following fact : the experimental shear apparatus has a failure surface smaller than the real one which averages all the strengh defaults [SOM 80].

### 3 LOCAL STABILITY INDEXES

At each point of the snow cover the stress state can be caracterised by their main stresses and the Mohr circle. Using a Mohr Coulomb criteria for the shear rupture superpposed to a tension criteria, we can represent the two rutpure mode currently admitted. The instability can be obtained when the Mohr circle at each point of the slope is going through the 2 behaviour curves [BOU 96, SCH 97] (figure 3].

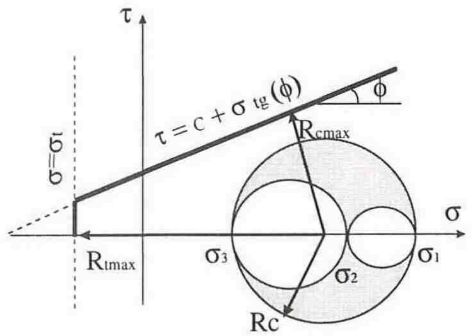



*figure 3 : stress state and rupture criteria*

We can define 2 indexes, one regarding the shear intablity and the other one for the tension instability :

$$F_c = \frac{R_{s\max}}{R_c} = \frac{\sin\Phi(2C\cot g\Phi + \sigma_1 + \sigma_3)}{\sigma_1 - \sigma_3},$$

$$F_t = \frac{R_{t\max}}{R_c} = 2\frac{\sigma_1 + \sigma_3 - \sigma_t}{\sigma_1 - \sigma_3},$$

where $R_c$ is the radius of the Mohr circle representing the stress state $R_{smax}$ and $R_{tmax}$ are the maximun circle radius possible regarding shear and tension.
Instability is then assumed when the indexes are les than 1. This can be calculated at each point by using the code FLAC3D calculating the stress state in each meshed layer of the snow cover. The code uses a finite differences method for the stress-train calculation [BIL 93].

### 4 FIRST RESULTS

We choiced to modelize a typical instable slab cover.
The meshed slope is a 100 m long, 40 m large combe with a slope angle of around 35°, and the rayon of the combe curvature slope is round 65 m (3m depth at the maximum slope ligne).
The snow cover has a 3 layers (figure 4), with a constant depth and the following caracteristics : hupper layer is new snow, layer mediane is 100 cm hard snow, layer under is 20 cm soft weak snow (critical layer) and last bottom one is 100 cm intermediate (or old) snow . The new snow representes the overloading (no, 50 cm, 1 m). We are interessed by the values of indexes in both slab (tension) and soft snow (shear) so the most bottom layer has no influence on the upper layers 's stress state .

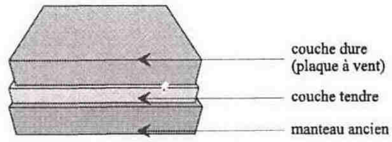



*figure 4 : a slab snow cover*

The mesh used is a symetrical one (half of the versant is calculted) divided into 20 zones in the large, per 40 zones in lenght and as needed zones of 20 cm in each depht layer.(figure 5)

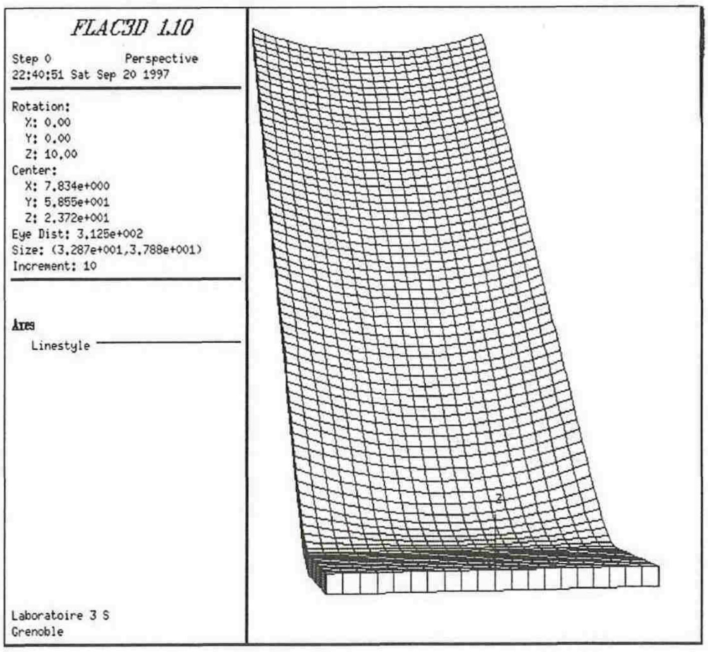



*figure 5 : 3D mesh of the modellized slope*

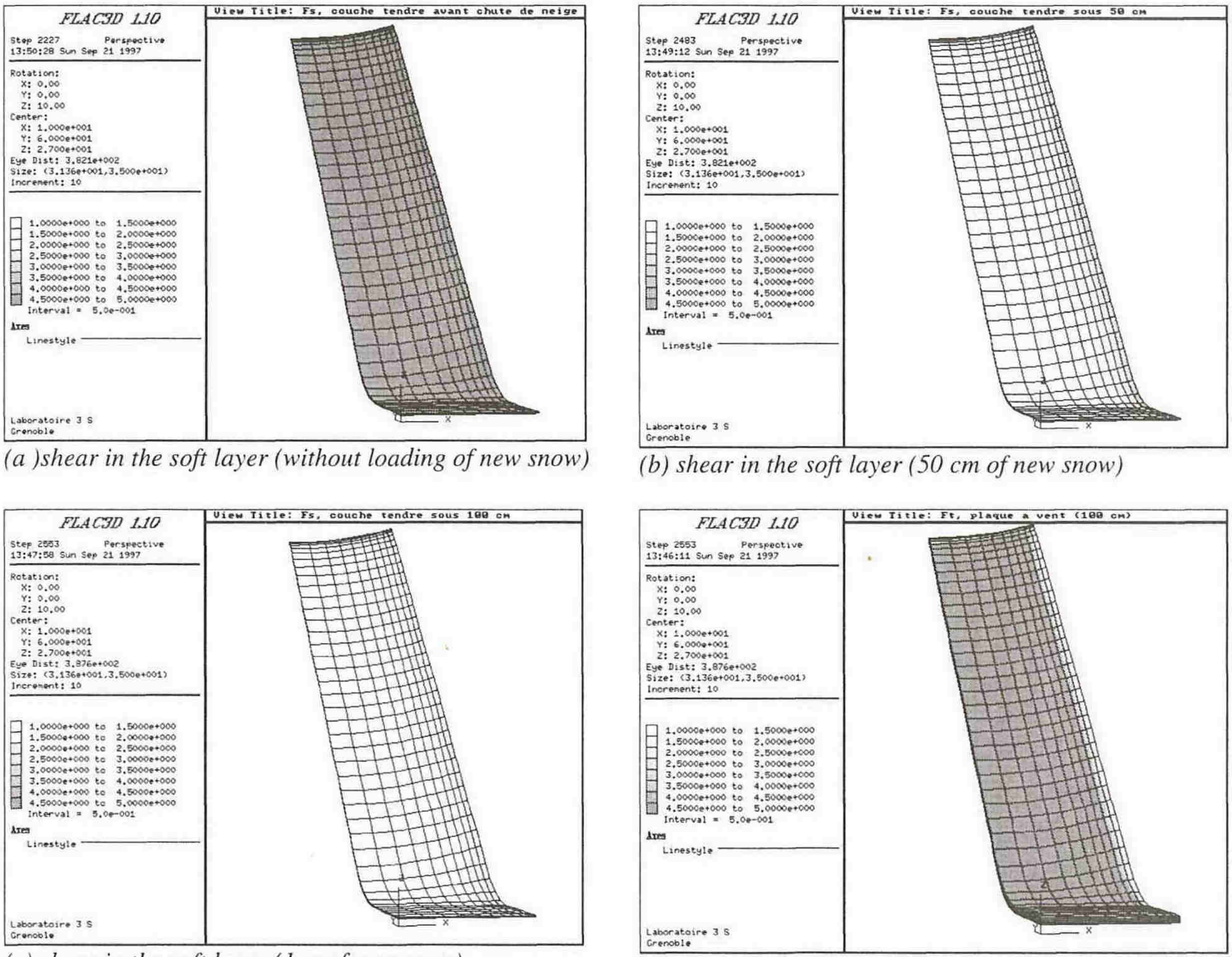
Limits conditions are a perfectly rigid soil under the snow cover avoiding a general packing down. All the layers are moving together and there are no interfaces glidding conditions. And the snow cover is encastred at the hupper, and lateral sides : vertical packing down is authorized. In the back end of the meshed snow there is simply a long horizontal snow cover continuation to simulate a soft limite, and authorizes some displacements (according to snow elastic properties) except lateral horizontal ones.

The brittle behaviour properties, which are more convenient regarding the speed range of the ruture phenomena [LAC 89], could'nt be taken into account due to the stress concentration, so only elasticity is and plasticity is used to solve the numerical problem and to find the stress state. So, the behavior law is an elasto plastic one (mohr coullomb criteria) ; and elastic constants are taken into the litterature, [MEL 75] (table 1):

We have plot the map of $F_s$ ans $F_t$ for the slab and the hupper layer for different overloading of new snow (figure 6a,6b,6c,6d). The darker the color is, the more stable the area is. We consider the the area is probably instable if the indexes are below the value 2. That means that we take a security coefficient of two. As seen in situ, the calculs shows that the slab in instable in tension near the crest and lateral side, and the critic layer is instable in shear in all the area [SCH 97]. The more is the over loading the more is the instability : without new snow the slab seems to be stable, and the 50 cm thick of new snow is anougth to lead to shear instability in the soft or weak layer .

| snow type | ρ (kg/ m3) | C (k Pa) | ϕ (°) | σt (kPa) | E (MP a) |
|---|---|---|---|---|---|
| soft snow (N1) | 100 | 0,4 | 23 | 0,4 | 0,22 |
| intermediate snow (N2) | 200 | 1 | 26 | 2,09 | 1,7 |
| hard snow (N3) | 300 | 8 | 46 | 5,52 | 15 |
| new snow (NF) | 150 | 1 | 24 | 1,05 | 0,5 |

*table 1 : mecanical constants used*




*(a )shear in the soft layer (without loading of new snow)*

*(b) shear in the soft layer (50 cm of new snow)*

*(c) shear in the soft layer (1 m of new snow)*

*(d) tension in the slab (1 m of new snow)*

*figure 6 : maps of the stability index in the layers*

## 5 Conclusion

Those encouraging results have been confirmed by other calculations of the four classical instable cases [ANC 96], even if they are not so spectacular, and need more adjustement of the mecanical constants to take into account.
A large field of research could be explored by using other come complicated behavior law (viscosity, plasticity...). This leads to the problem of mecanical in situ constant to introduce, variability to take into account. But because calculus can be done numerously without danger, a large parametric study can be used espacially for geometrical effects (changes of slope, of depth, of resistance, effet of threes...). And the confrontation with all the regular fields observations made schould be done to confirm the accurancy of the calculus 's results.

## Aknowledgements

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## Bibliography

[ANC 96] ANCEY C. , « Guide neige et avalanches : connaissances, pratique, sécurité (EDISUD) 317p

[BIL 93] BILLAUX D., CUNDALL P.Simulation des géomatériaux par la méthode des éléments Lagrangien, Rev Franc Géotech n°63 , avril 93, p 9-21

[BOU 96] BOULON M. :Computation of safety factors (Plaxis course : safety factors 08.01.1996 15.01.1996) 19p

[CON 84] CONWAY,H. and J. ABRAHAMSON : Snow stability index (J Glaciol., 30(106) 1984) 321-327

[FOH 86] FÖHN, P.M.B. : The stability index and various triggering mechanims (Proceedings of the Davos symposium, 09.1986) 199-205- IAHS Publ.n°162,1987.

[JAM 93] JAMIESON J. B. and JOHNSTON C. D. : Shear frame stability parameters for large-scale avalanche forecasting (A. Glaciol 18 1993) 268-272

[LAC 89] LACKINGER B. Supporting forces and stability of snow slab avalanches : a parameter study (A. Glaciol. 13, 1989) 140-145.

[MEL 75] MELLOR, M : A review of basic snow mechanic. IAHS Publication 114 (symposium at Grinelwald 1974), 251-291.

[ROC 66] ROCH A. Les variations de résistances de la neige- Publication n°69 de l'AIHS, Symposium international sur les Aspects scientifiques des Avalanches de neige , 86-99.

[SCH 93] SCHWEIZER J. : The influence of the layered character of snow cover on the triggering of slab avalanches (A. Glaciol., 18 1993) 193-198

[SCH 97] SCHILLINGER L. Modélisation numérique de la stabilité des plaques de neige, Rapport de DEA, Université Joseph Fourier, Grenoble, sept 97, 47p.

[SOM 76] SOMMERFELD R.A. A correction factor for the roch's stability index of slab avalanche release. (J. of Glaciol. ,. 17 (75), 1976) 145-147.