Arresting and Deflecting Snow Avalanches

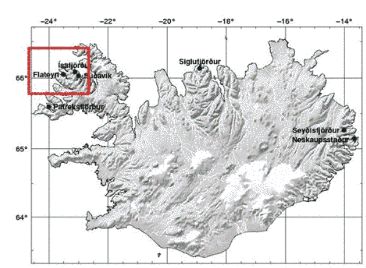
Andrew Hogg,
Kristin Martha Hákonardóttir

Centre for Environmental & Geophysical Flows
Department of Mathematics
University of Bristol

Thomas Jóhannesson

Icelandic Meteorological Office

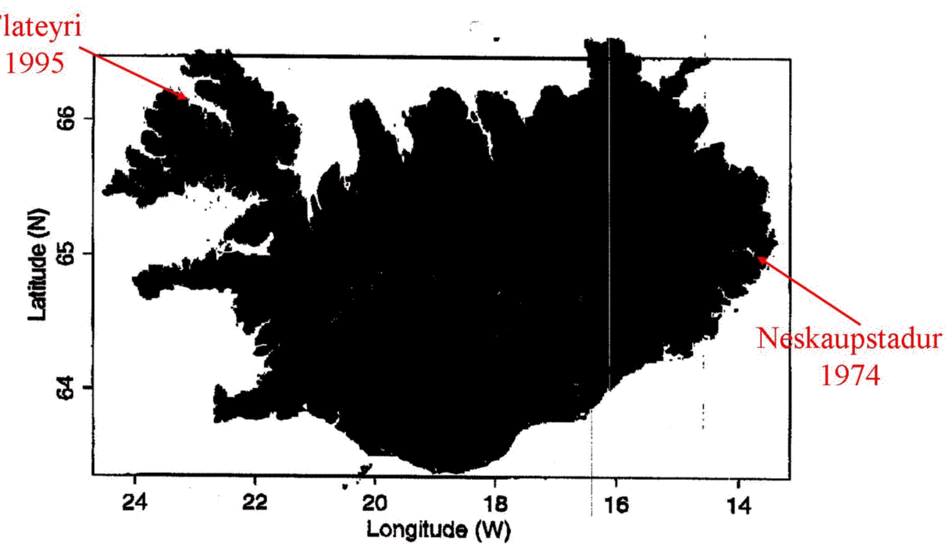
Flateyri (NW Iceland)



- New housing at base of mountain gulley
- Some conical mounds to arrest avalanches

- On 26 October 1995 a large volume snow avalanche struck Flateyri.
- 20 fatalities; third most serious avalanche accident in Icelandic recorded history.
- All bar one of the destroyed houses outside of the declared avalanche-danger areas.

Snow Avalanche occurrence



Various defence schemes employed:

- Village relocation; Evacuation procedures; Snowpack stabilisation.
- Deflecting dams; Braking mounds.

Snjóflóðavarnir á Íslandi

tryggt fjármagn til þess, en heildarkostnaður er lauslega áætlaður 10-20 milljarðar króna. Um leið hafa rannsóknir tengdar snjóflóðum verið stórefldar og þróaðar nýjar aðferðir við gerð hættumats, sem hlotið hafa athygli víða erlendis.

Varnargarður á Flateyri

Fyrsta verkefnið eftir náttúruhamfarirnar á árinu 1995 var bygging varnargarða á Flateyri. Þar var þá líklega allra mesta snjóflóðahætta á byggðu bóli hér á landi og þótt víðar væri leitað. VST sá um alla hönnun garðanna nema hvað snjóflóðatæknileg hönnun þeirra var í samvinnu við norsku jarðtæknistofnunina (NGI).

Hönnun garðanna varð strax í upphafi fyrir órökstuddri og á stundum mjög óvæginni gagnrýni, þar sem virkni þeirra var dregin alvarlega í efa. Þær raddir hafa þó algjörlega þagnað, enda hafa garðarnir þegar sannað gildi sitt þrátt fyrir ungan aldur. Með aðeins árs millibili féllu stór snjóflóð, sitt á hvorn leiðigarðinn, þann 21. febrúar 1999 úr Skollahvilft á eystri garðinn og þann 28. febrúar 2000 úr Innra-Bæjargili á vestari garðinn. Í báðum tilfellum reyndi verulega á garðana, enda eru flóðin talin hafa endurkomutíma á milli tíu og þrjátíu ár hvort um sig og verður að teljast tilviljun að svo stór flóð falli á báða garðana svo stuttu eftir byggingu þeirra. Talið er að án varnargarðanna hefðu bæði flóðin náð inn í byggðina eins og hún var fyrir 1995, og flóðið á þessu ári hefði að öllum líkindum farið yfir hús sem enn er búið í. Hönnunarforsendur garðanna stóðust þessa prófraun fullkomlega og gögn sem safnað var um flóðin og áhrif garðanna hafa vakið mikla athygli erlendis og munu hafa verulegt gildi fyrir hönnun leiðigarða í heiminum.

Óhefðbundnar varnir

Við Neskaupstað er einnig hafin bygging snjóflóðavarna sem eru að mörgu leyti óhefðbundnar að gerð. Snjóflóðatæknileg hönnun þeirra er í höndum VST, í samvinnu við CEMAGREF í Frakklandi. Þar er blandað saman varnarvirkjum á upptakasvæði snjóflóða og á úthlaupssvæði þeirra. Slík útfærsla er nánast óþekkt í heiminum, en hefur ótvíræða kosti í Neskaupstað. Þetta er auk þess í fyrsta sinn sem varnarvirki þessarar tegundar eru byggð hér á landi í einhverjum mæli, það er stoðvirki á upptakasvæði snjóflóða og snjóflóðakeilur og þvergarðar á

Séð frá byggðinni upp til varnargarðanna á Flateyri.

Tölvuteikningar af þvergarði og snjóflóðakeilum í Neskaupstað sem nú eru í byggingu.

Höfundar:

Gunnar Guðni Tómasson: Yfirverkfræðingur á þróunar- og umhverfissviði VST og sérfræðingur í straumfræði. Fæst m.a. við straumfræðilega hönnun mannvirkja, gerð og notkun reiknilíkana í straumfræði og umhverfisverkfræði, virkjanir, hafnargerð, strauma í sjó, ám og vötnum, dreifingu mengunar, áhættumat og varnir vegna snjóflóða.

Flosi Sigurðsson: Verkfræðingur á þróunar- og umhverfissviði VST. Fæst við hönnun burðarvirkja úr steinsteypu, stáli og timbri, jarðskjálftagreiningu burðarvirkja, hönnun dreifikerfa vatnsveitna og regnvatnslagna, útboðsgagnagerð og kostnaðaráætlanir, verkefnisstjórnun, hættumat vegna snjóflóða og hönnun snjóflóðavarna.

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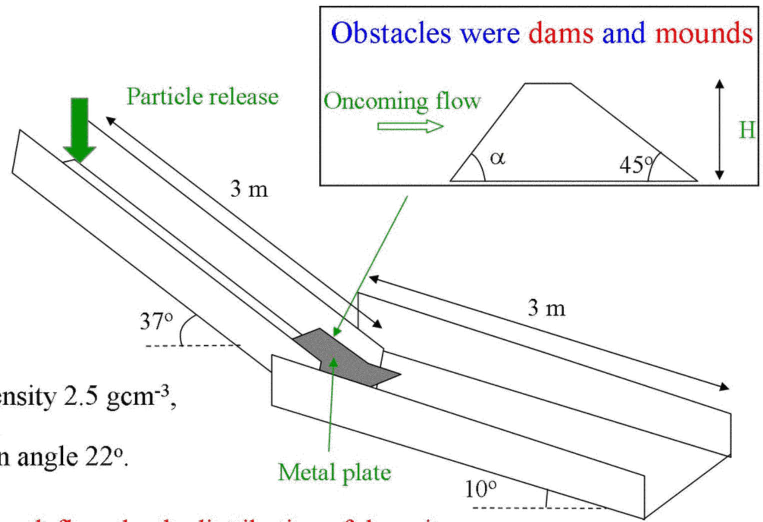
Rapid flow Experiments

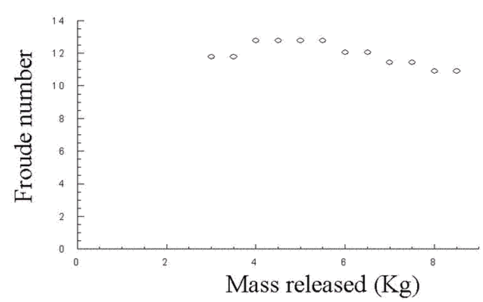
- The apparatus



- Glass ballotini particles
  - diameter 100μm, density 2.5 gcm^{-3}, angle of repose 26°, dynamic bed friction angle 22°.
- Mass released 3-8 Kg
- Measurements of flow speed, flow depth, distribution of deposit
  - using analysis of video recordings, tracer particles, depth gauges

The flow on the upper chute

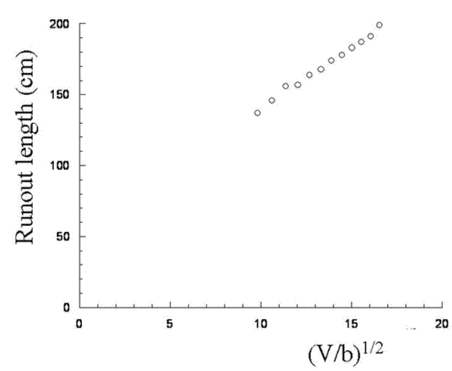
- The flow rapidly attains a terminal velocity.
  - The material travels as a "hummock" shape, with the front moving faster than the following stream.
  - Constant Froude number ($F=U/(gh)^{1/2}$)



Balance drag and gravitational forces

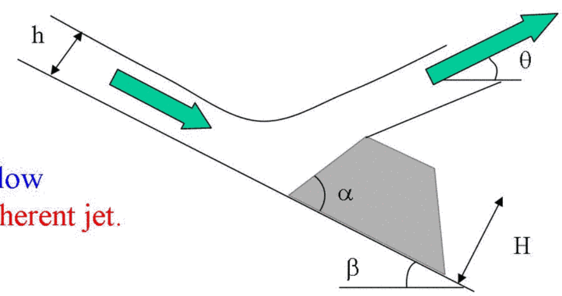
$$C_D u^2 = g(\sin\theta - \cos\theta\tan\delta)h$$

- Runout length proportional to $(\text{Volume/breadth})^{1/2}$ but deposit is layered.

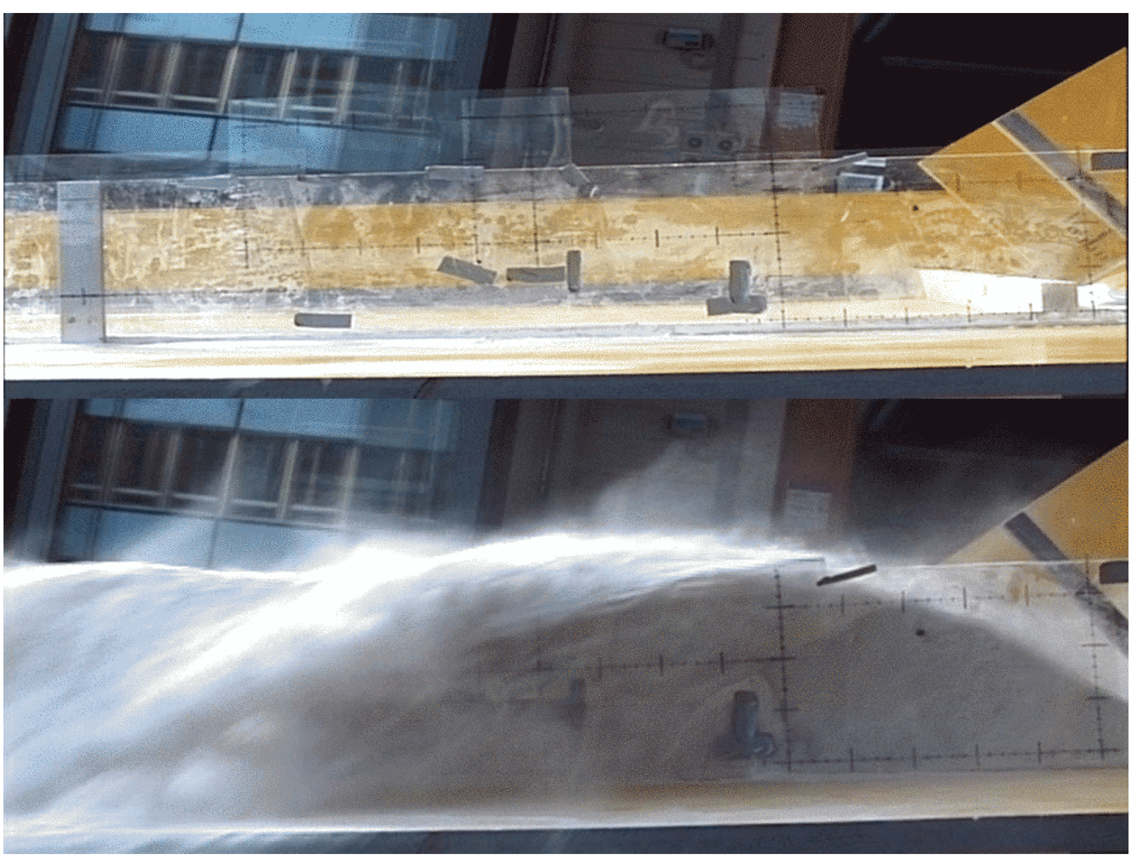


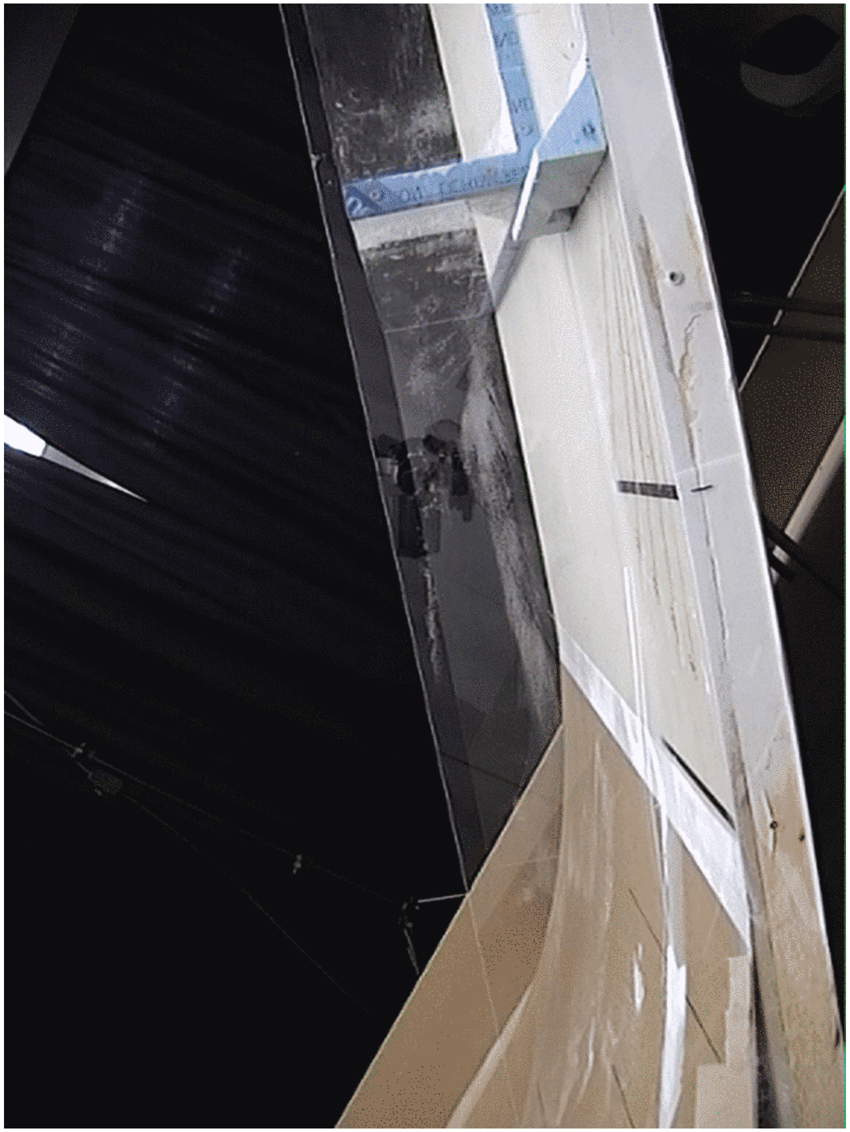
Jet formation

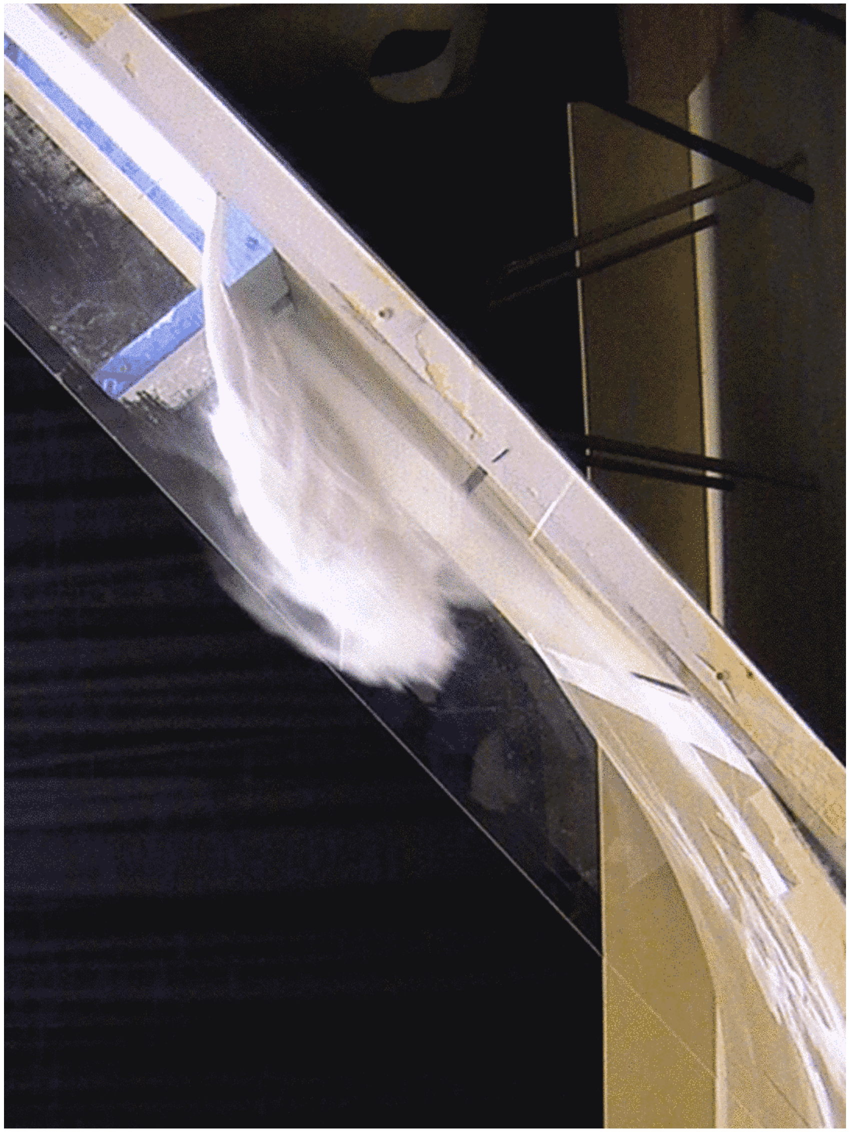
- The height of the obstacles varied in the range $1<H/h<7$



- On striking the dam/mound, the flow became airborne and formed a coherent jet.







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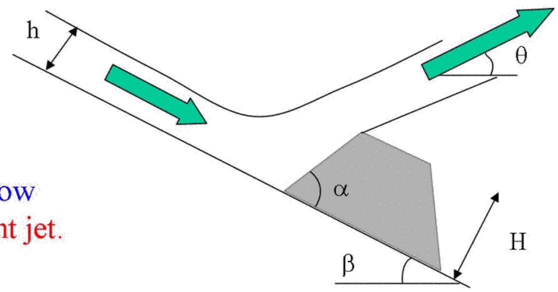
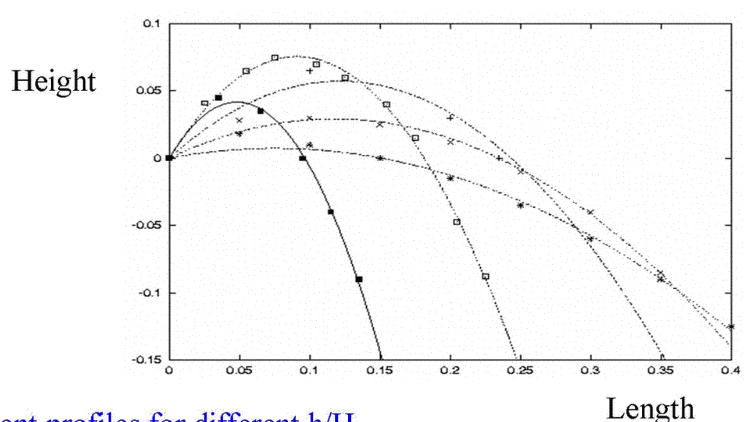


- On striking the dam/mound, the flow became airborne and formed a coherent jet.

- The jet trajectory is not affected by air resistance.
  - It takes a parabolic shape.
  - The horizontal component of velocity is constant.
- The throw angle $\theta = \text{fn}(\alpha, h/H)$
  - expect that $\theta \to \alpha - \beta$, as $H/h \to \infty$.

Jet profiles

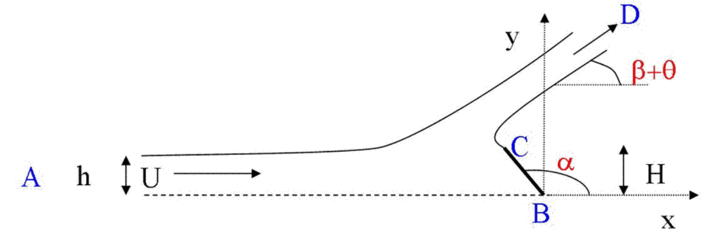
- Motion of particles in jet only influenced by gravitational forces



- Different profiles for different h/H

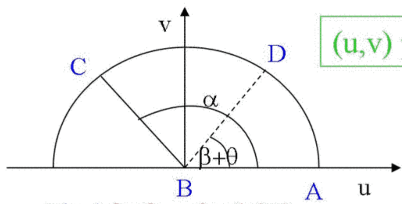
- Hence it is possible to predict:
  Jump Length, Jump Height etc.
  - important implications for avalanche defence measures.

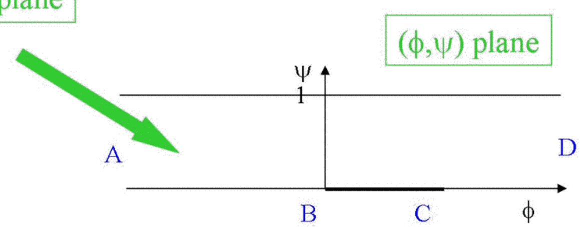
The deflection of inviscid, irrotational jets



- Using conformal mappings it is possible to deduce an analytical expression for the complex potential in the absence of gravity ($U^2/gh >> 1$, $h/H = O(1)$)
- Scale velocity *w.r.t.* U and lengths *w.r.t.* h
- Write complex potential

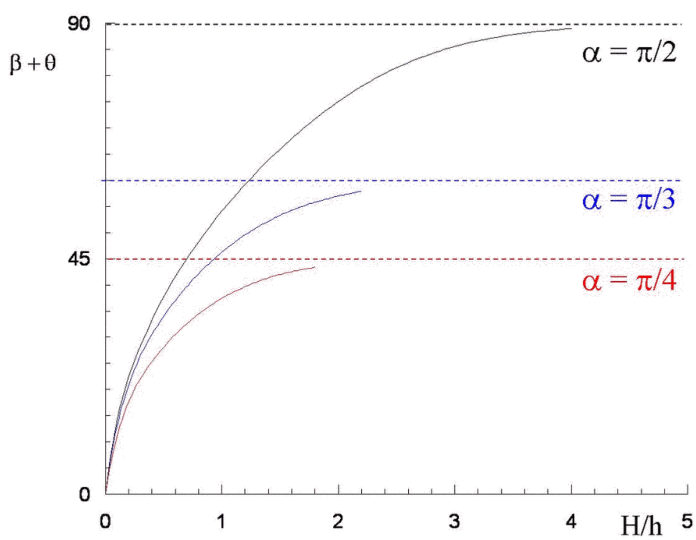
$$W(z) = \phi + I\,\psi\,, \quad \text{with } dW/dz = u - I\,v, \quad \mathbf{u} = (u,v)$$





- Find $\theta+\beta = \text{fn}\,(h/H)$

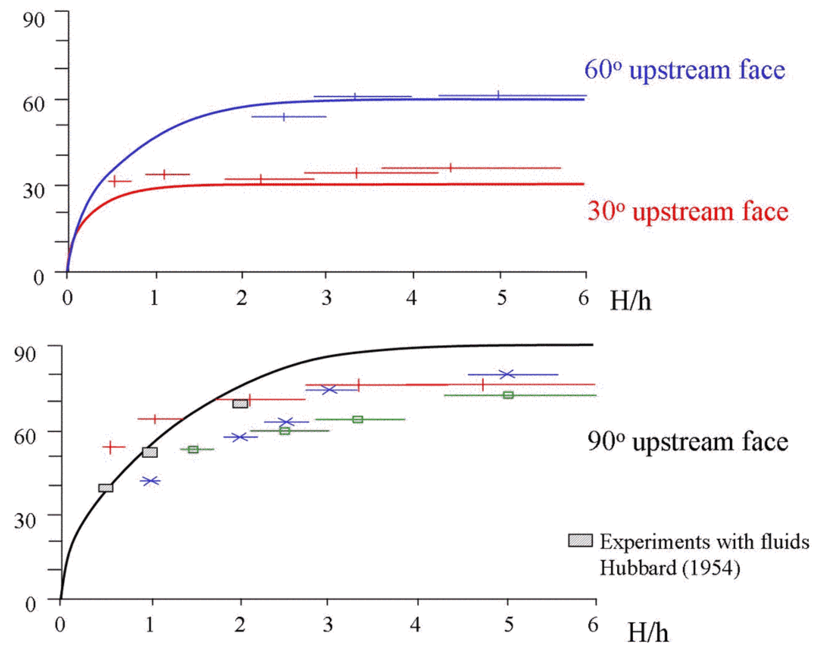
Jet deflection – theoretical results

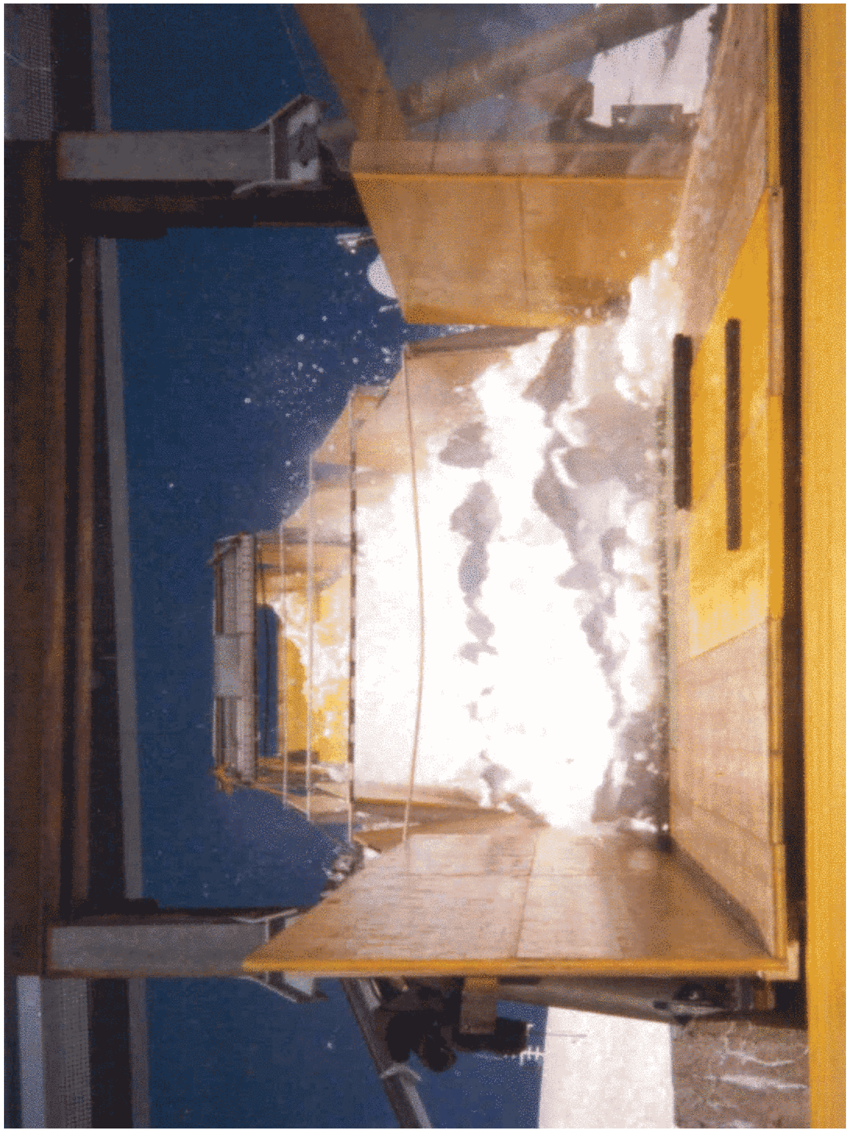


Full deflection as $H/h \rightarrow \infty$

Jet deflection - results

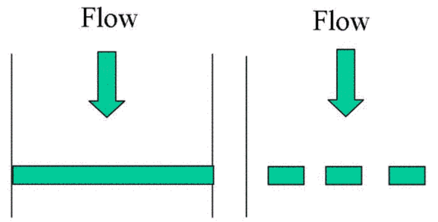
- Comparing these inviscid, irrotational, gravity-free results for fluid motion with experimentally- measured deflection of a rapid granular flow:



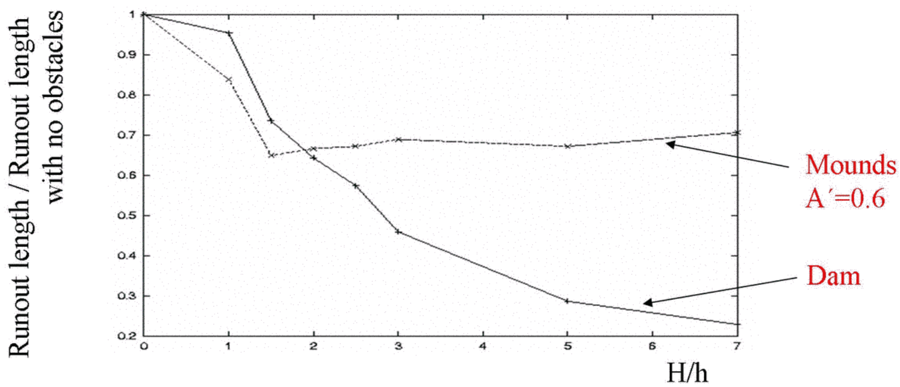


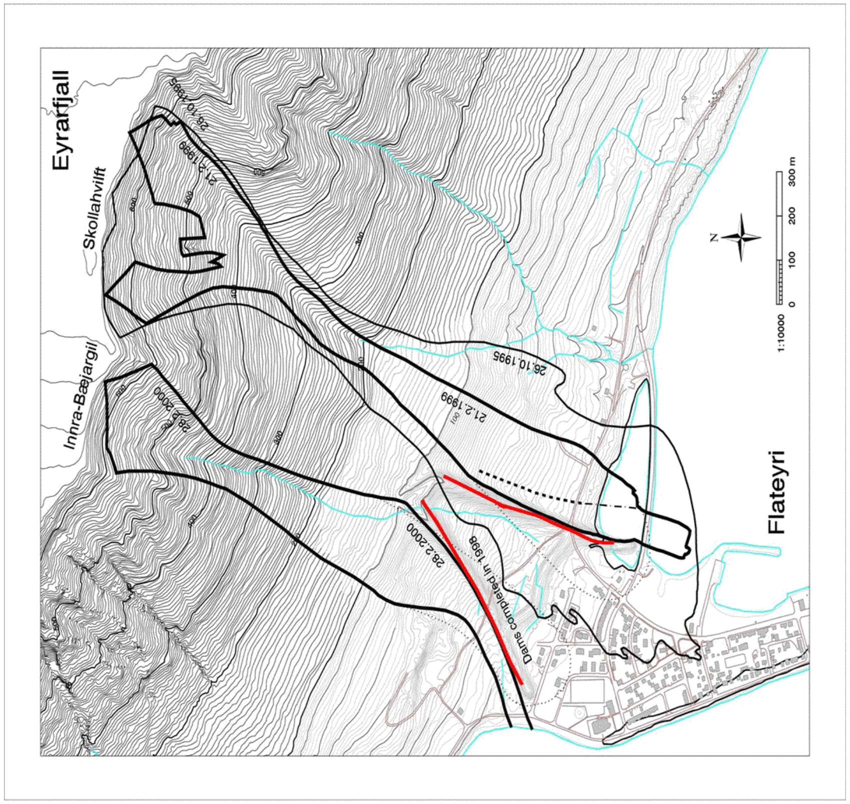
The effect of obstacles on runout

- The effect of the obstacle height
- Dams *vs* Mounds: plan view of obstacles

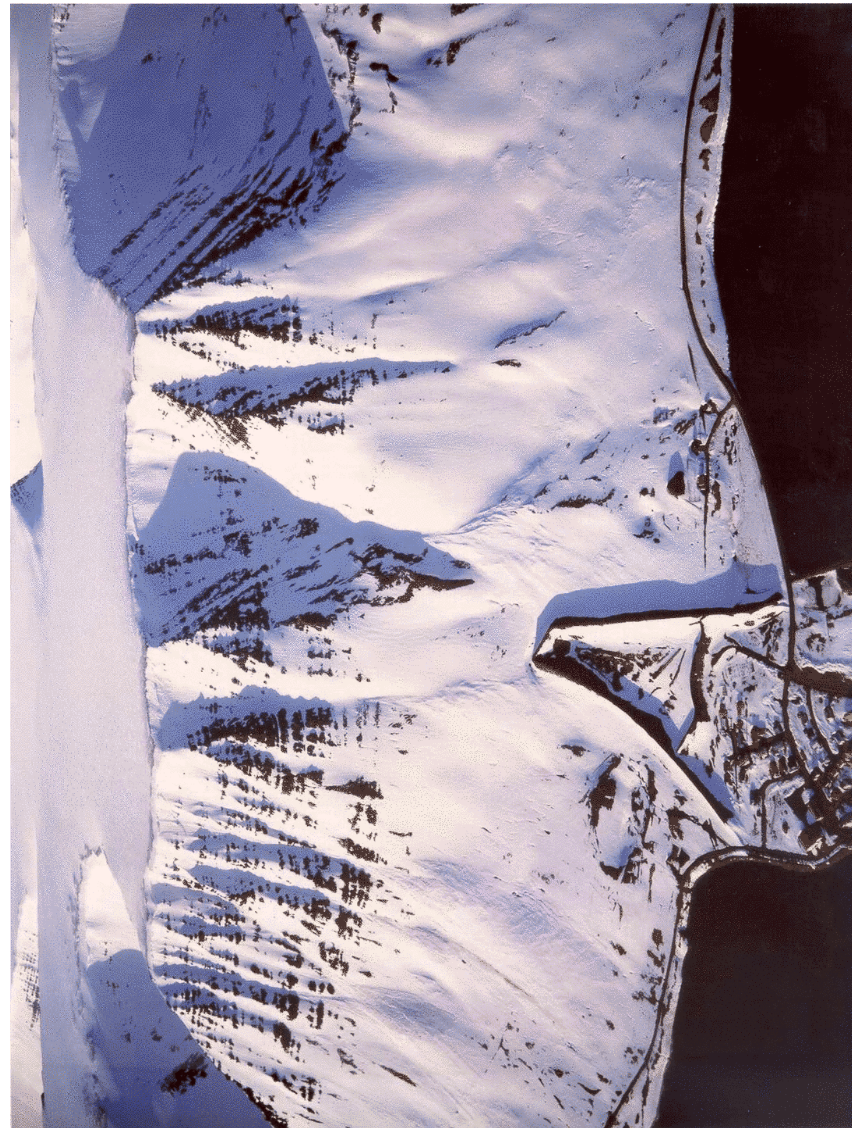


- A′ = Proportion of chute cross-sectional area filled by obstacles
  - A′ = 1 for dam, A′ < 1 for mounds (often A′=0.6).



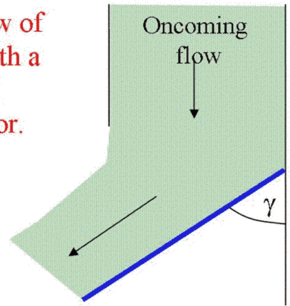


Deflecting Dams
at Flateyri



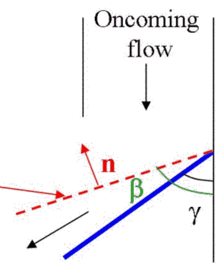
Experiments with deflecting dams

Plan view of chute with a rigid deflector.



- Sustained releases of particles of glass ballotini to generate a high Froude number avalanche on the chute.
- Measure the flow and investigate its deflection by the dam.

Deflection Shock



- Once the steady-state is established, we find an abrupt change in flow depth across a line in front of the dam.
- Assuming hydrostatic pressure, it is possible to calculate the deflection angle:

Jump conditions across the shock:

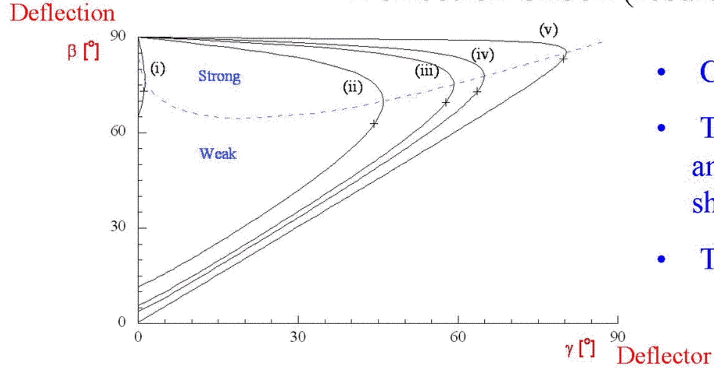
$$[h(\mathbf{u}.\mathbf{n})]_-^+ = 0 \qquad \left[\tfrac{1}{2} g h^2 \mathbf{n} + h(\mathbf{u}.\mathbf{n})\mathbf{u}\right]_-^+ = 0$$

Mass flux　　　　Momentum flux

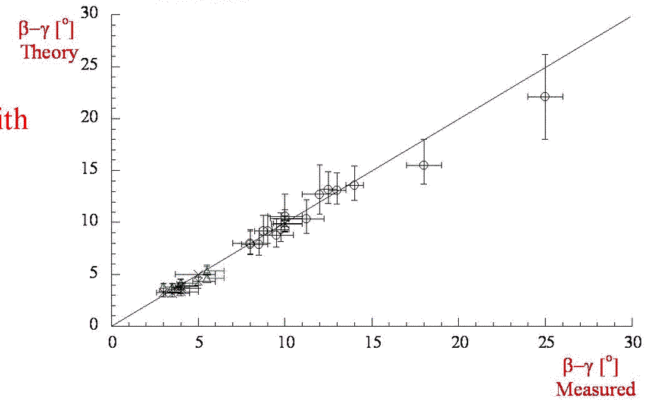
- Determine the deflection angle, β; the jump in flow depth; the downstream flow speed as function of:
  - Deflector angle, γ
  - Upstream Conditions U_1, h_1

Froude number $$F = \frac{U_1}{\sqrt{g \cos\theta \, h_1}}$$

Deflection Shock (results)



- Curves for different F
- There is a maximum deflector angle (γ_m) for which an attached shock can be found
- Two deflection angles for $\gamma<\gamma_m$



- Experiments carried out with different upstream Froude numbers & with flows of water and grains.