UNIVERSITY COLLEGE DUBLIN

School of Architecture, Landscape and Civil Engineering

Effect of Climate Change On Slope Stability Problems

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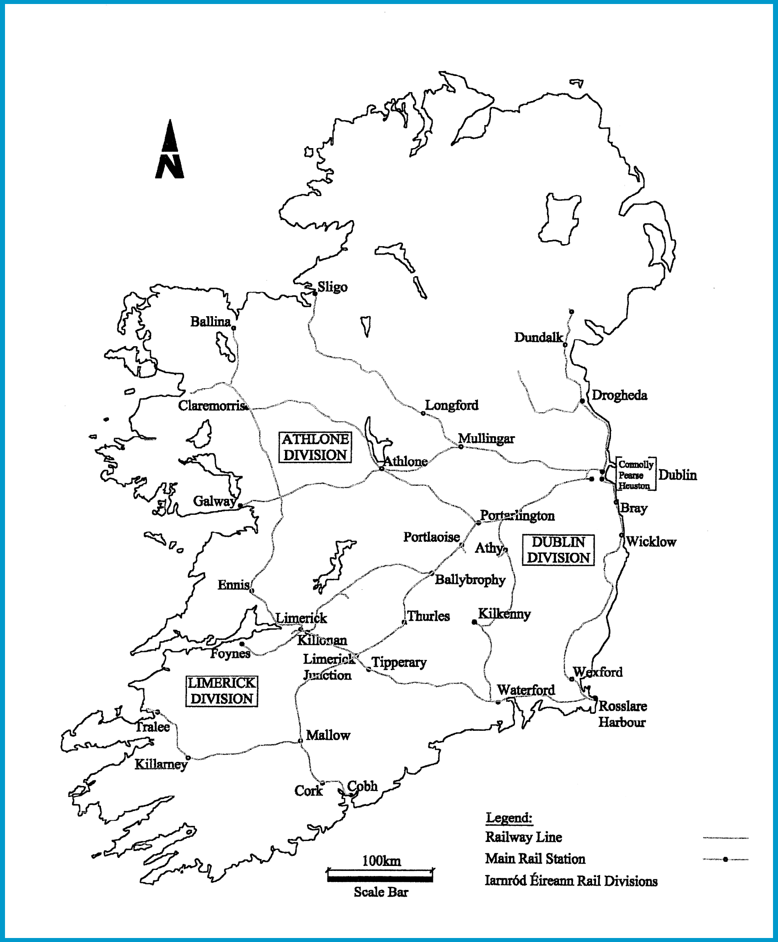
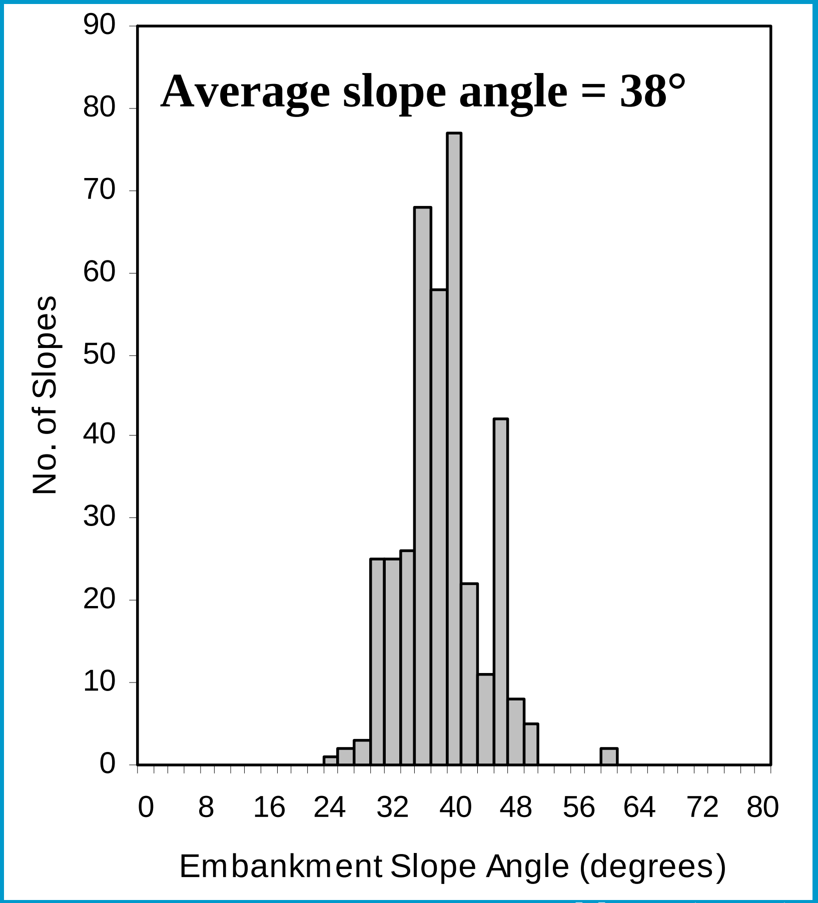
Outline of the Presentation

- Glacial Till slopes in Ireland
- Description of Probabilistic Analysis
- Benchmarking & Conclusions
- Case Studies of rainfall induced slope failures

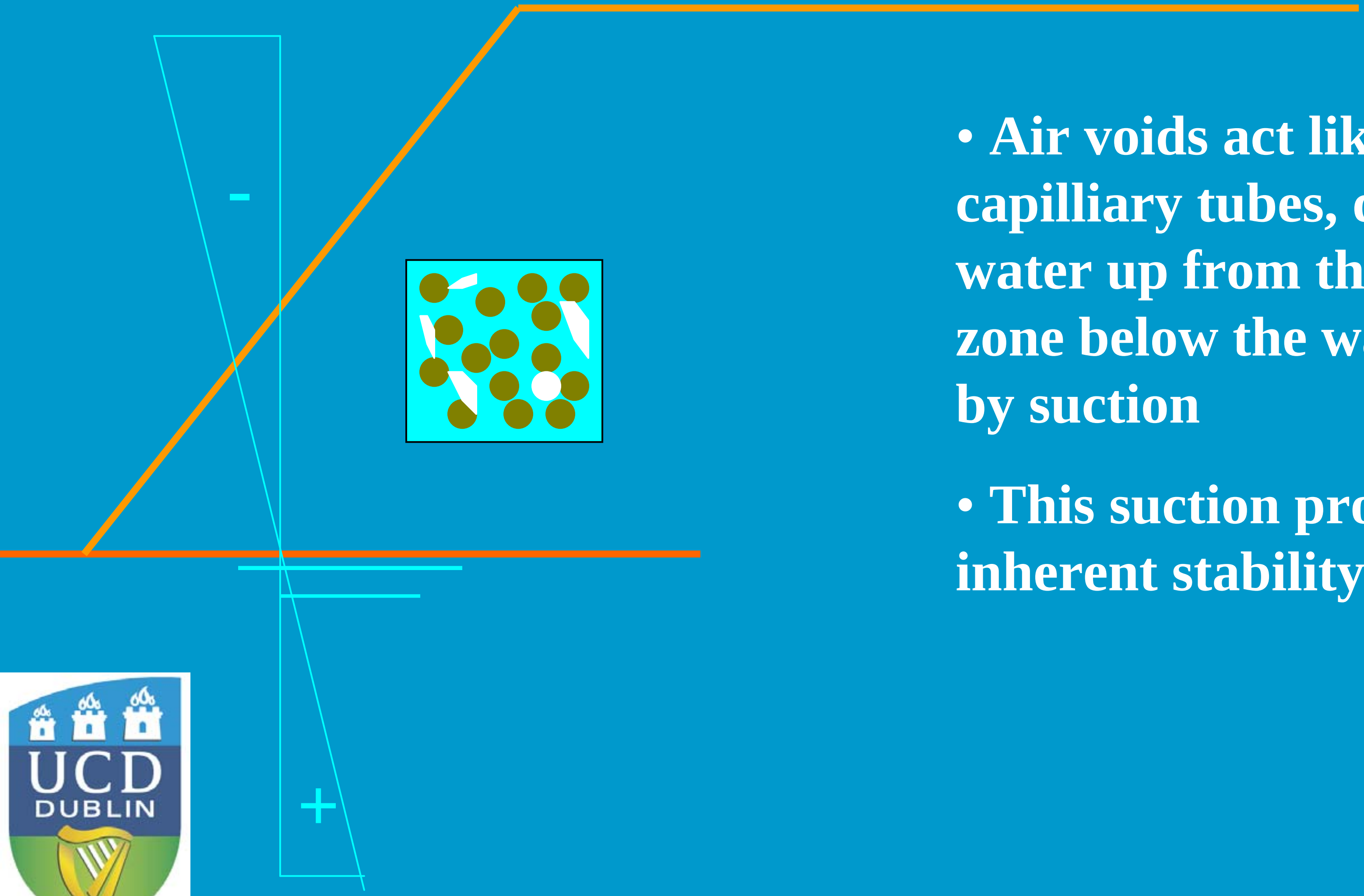
Survey of 150 year old railway embankments





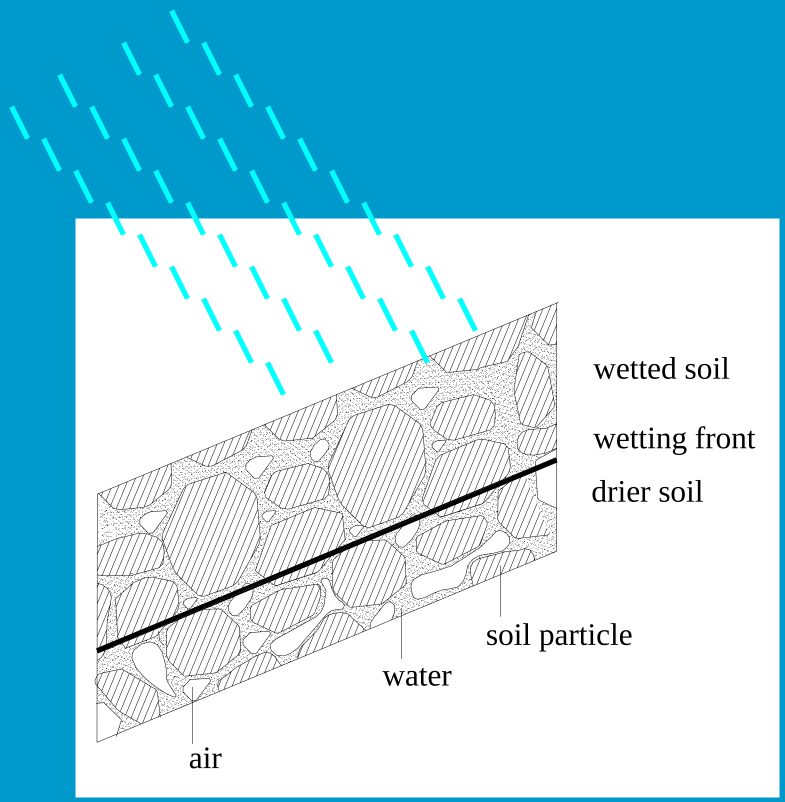
Jennings & Muldoon (2003)

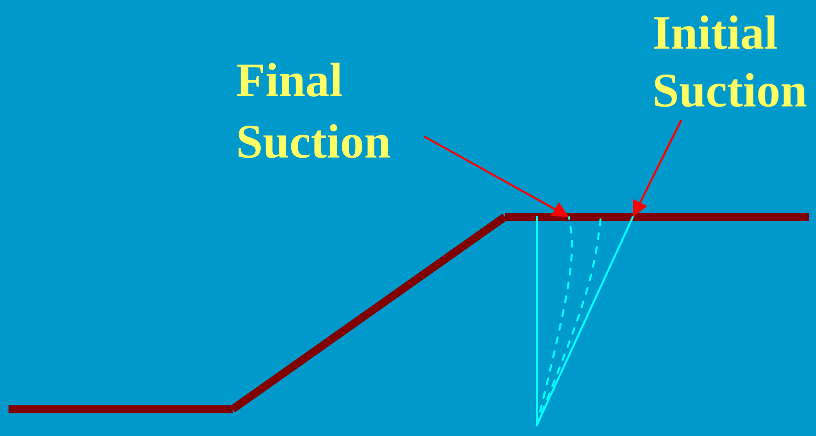
Slopes are Partially Saturated



- Air voids act like mini capilliary tubes, drawing water up from the saturated zone below the water table by suction
- This suction provides inherent stability

Stability is affected by rainfall

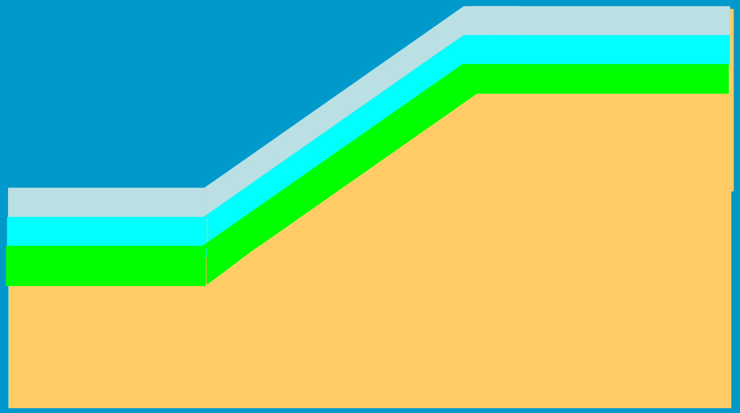




As rain falls, suctions reduce. A wetting front develops as the ground becomes *almost* saturated from the top down

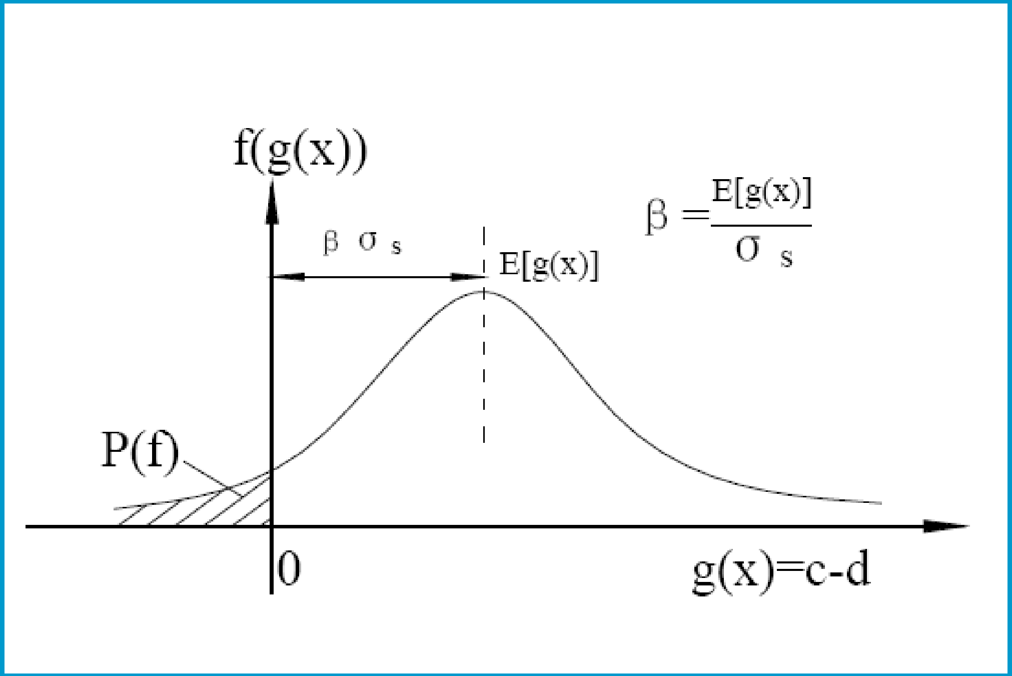
Effect of suction on slope stability

$$\text{FOS} = \frac{\text{Capacity}}{\text{Demand}}$$



- **Stability is provided by near surface suction (-pwp)**
- **Rainfall causes formation of wetting front (increased pwp) reduces suction and may cause failure – typically shallow slip**

Reliability Index



- Consider alternative form of performance function g(x):

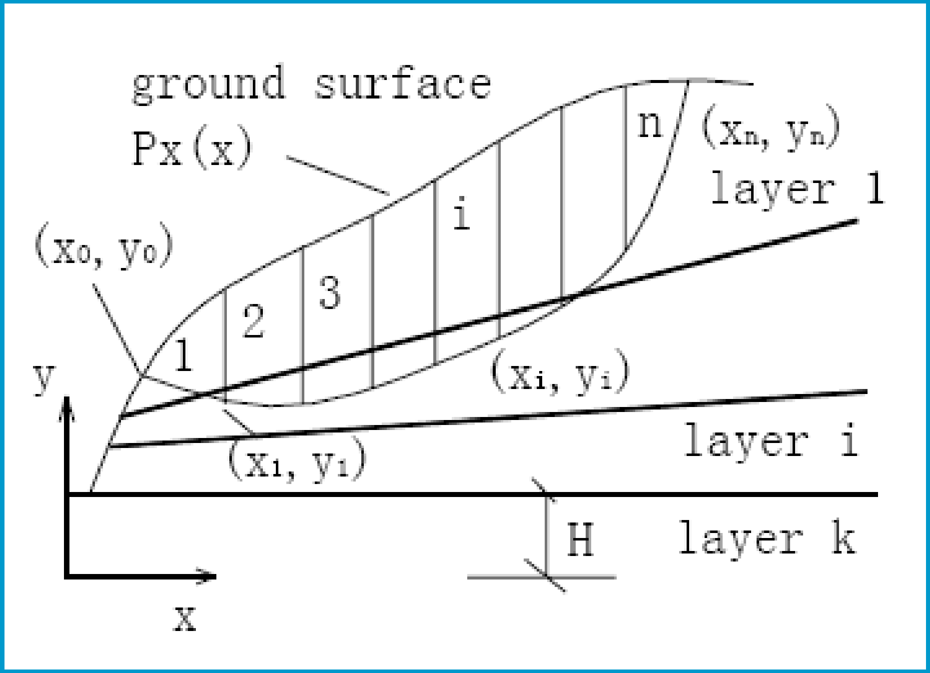
FOS= C / D

g(x) = C – D

If C – D ≤ 0, the slope has failed

- β is the mean of the performance function, divided by the number of standard deviations between the mean and origin – usually β = 2 is minimum acceptable

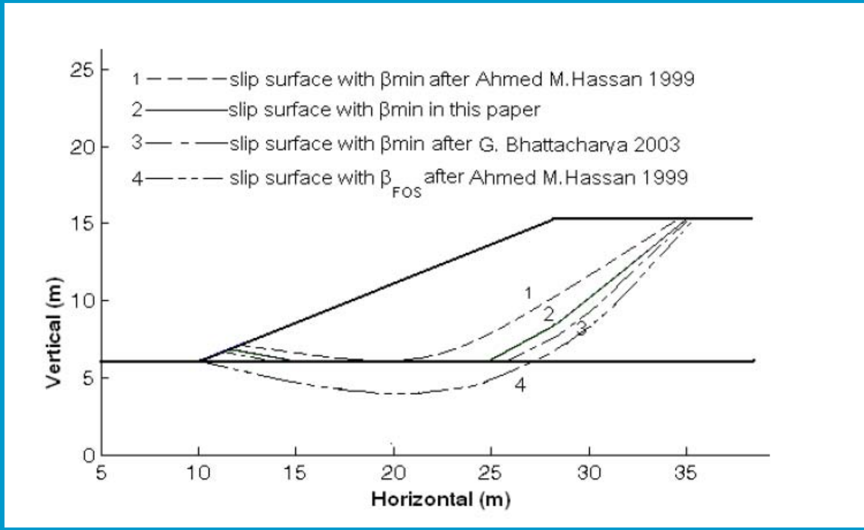
UCD Reliability Model - GASSA

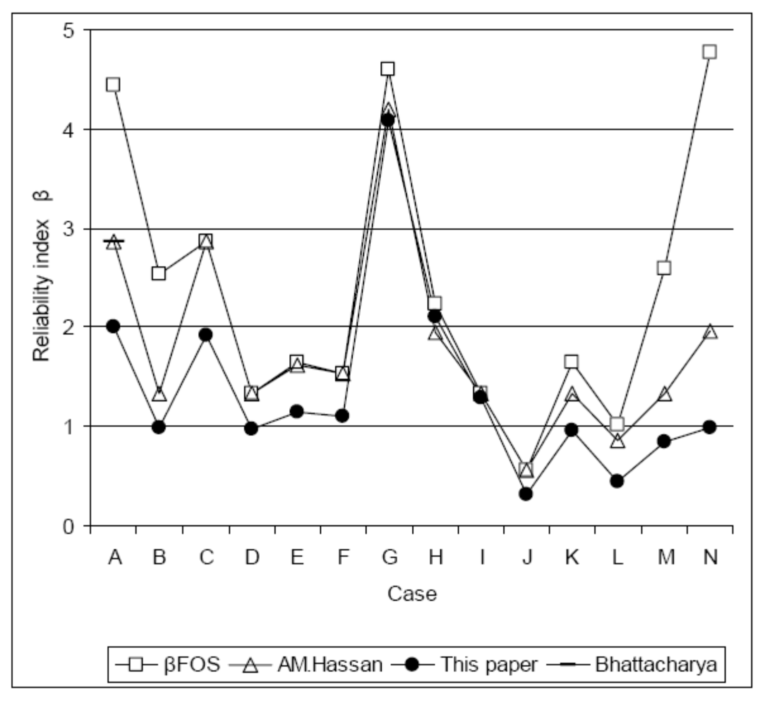


Geotech reliability analysis of slopes usually assumes fixed soil properties to determine critical slip surface and the varies soil properties along this fixed surface to determine reliability

By using polar transformation UCD consider soils properties and slip coordinates as variables and solves simultaneously, invariant and computationally efficient

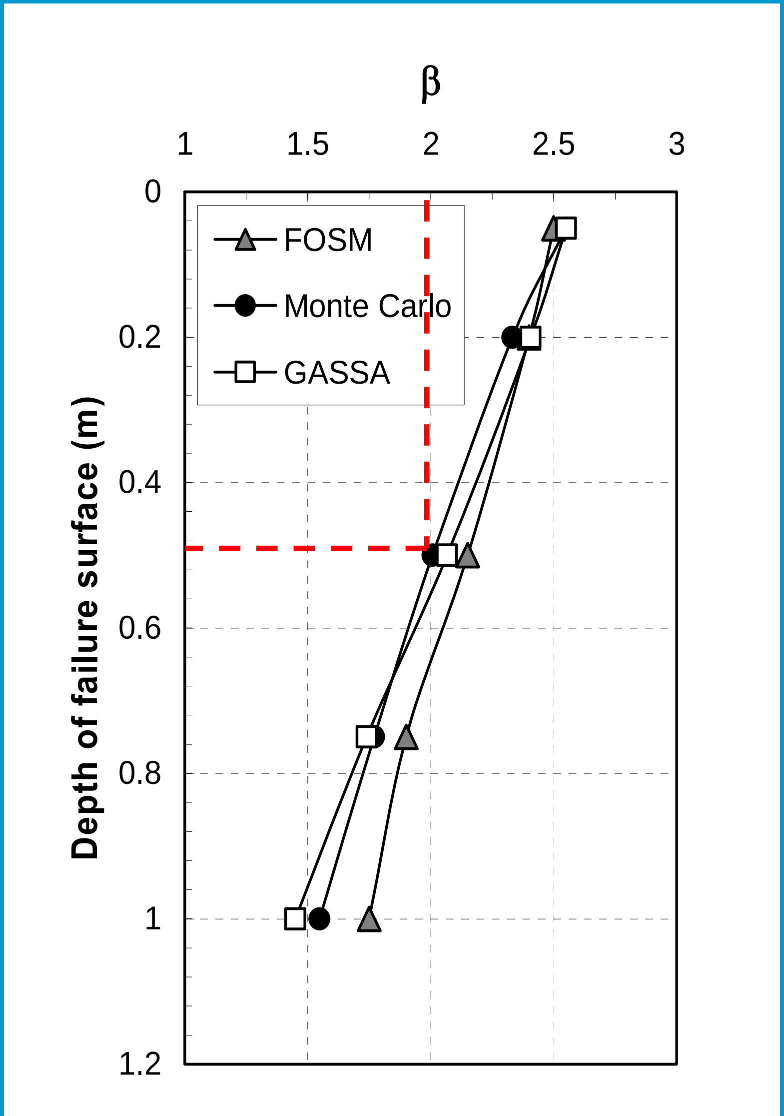
Performance of UCD model





- Method applied to benchmark 1:2 slope from the literature
- A range of soil properties Cases A-N were considered
- The relative performance of UCD model was best in all but one (Case H) of the fourteen soil profiles analysed, and in Case H all methods were broadly similar

Partially Saturated Slope Analyses

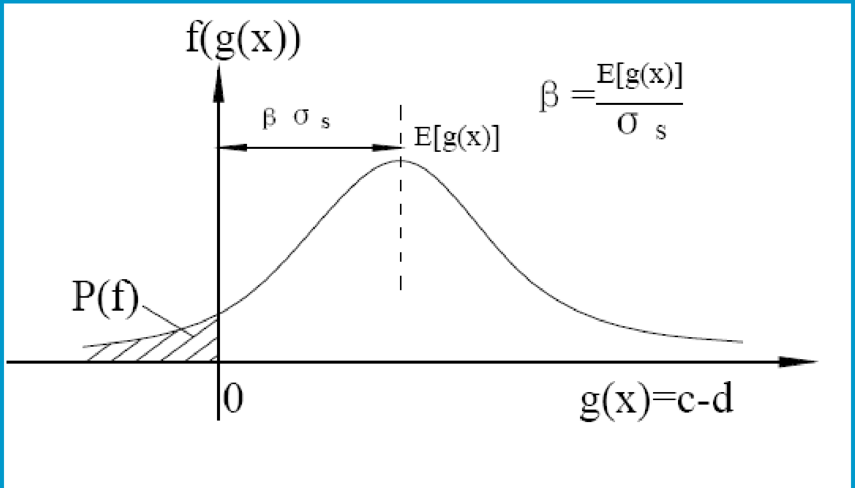


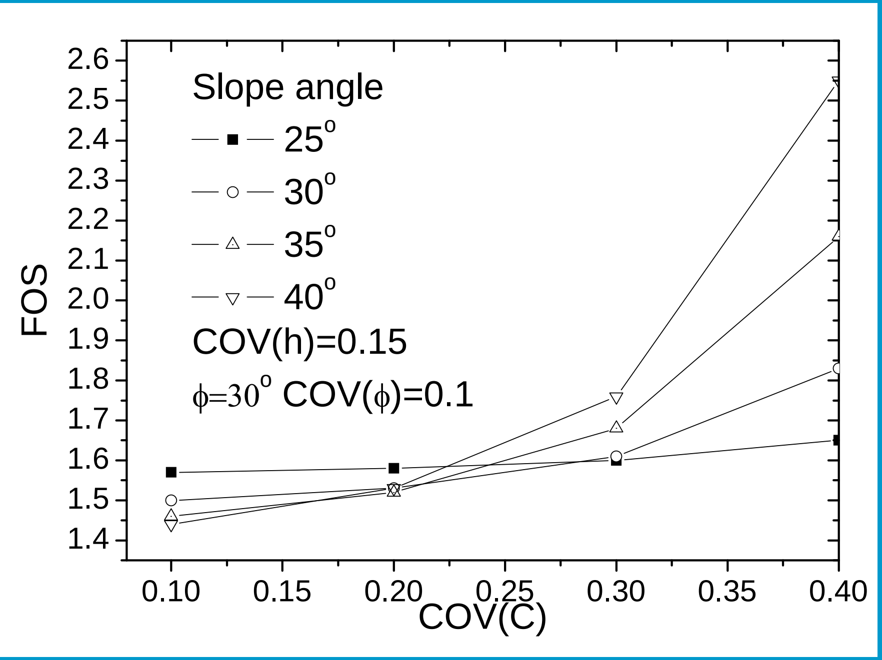
- Model used to asses the performance of an instrumented slope in the Swiss Alps

- Measurements of suction, rainfall intensity and soil strength parameters were available. 0.5 m deep failure occurred after 45 hours into infiltration test.

- GASSA and Monte-Carlo give very similar results. Both suggest critical conditions (β≈2) when the wetting front depth reaches 0.5m.

For Additional Uncertainty – Increase FOS





Possible reasons for additional uncertainty:

(i) Untypical ground conditions

(ii) Poor site investigation

(iii) Complicated stratigraphy

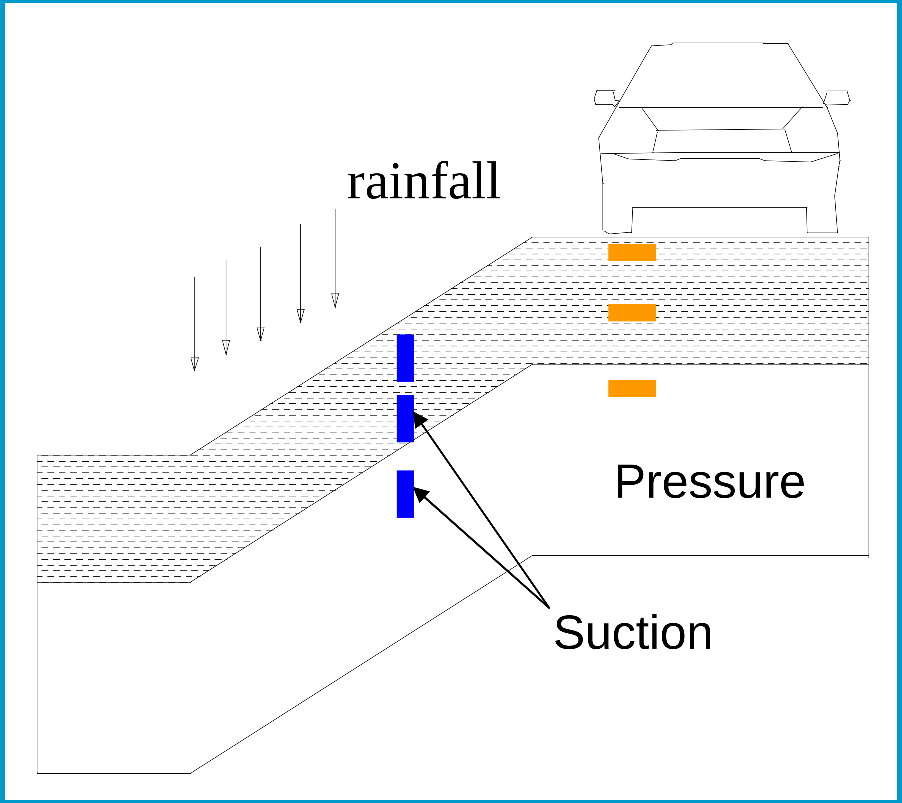
(iv) Lack of rainfall or other data

(v) Natural variability

Conclusions - Analyses of slopes

- A number of highly variable parameters control the stability of slopes
- Stability analysis is more suited to probabilistic rather than deterministic methods
- Probabilistic models are available
- Hybrid design approaches are also being developed

Stability of Infrastructure – Smart Slopes



- In-situ monitoring of suction and in-situ stresses
- Real time assessment of infrastructure reliability
- We cannot monitor every slope, we need to identify critical sections – Geophysics?

Recent Slope Failures

Rainfall Records

Extreme Rainfall Return Periods

Location: Gorey, Co. Wexford
Average Annual Rainfall: 982

Maximum rainfall (mm) of indicated duration expected in the indicated return period.

	Return Period (years)								
Duration	1/2	1	2	5	10	20	30	50	100
1 min				1.8	2.1	2.4	2.7	3.0	3.4
2 min				3.1	3.5	4.2	4.6	5.2	5.9
5 min				5.5	6.4	7.6	8.3	9.4	10.8
10 min				7.8	9.2	11.0	12.2	13.9	16.0
15 min	4.9	6.2	6.9	9.5	11.6	14.0	15.6	17.8	21
30 min	6.7	8.3	9.3	12.6	15.4	18.5	20.5	23	27
60 min	8.8	11.0	12.3	16.4	19.7	24	26	30	34
2 hour	11.8	14.3	16.0	21.1	25	30	33	37	43
4 hour	16.2	19.6	21.5	28	32	37	41	45	52
6 hour	19.7	23.6	26	33	38	44	48	53	61
12 hour	25.4	30	33	42	49	55	60	66	75
24 hour	32	38	41	51	59	67	73	80	90
48 hour	39	46	51	63	71	81	87	95	107
96 hour									

Notes: Larger margins of error for 1, 2 ,5 and 10 minute values and for 100 year return periods
M560: 16.4 M52d: 59 M560/m52d: 0.28

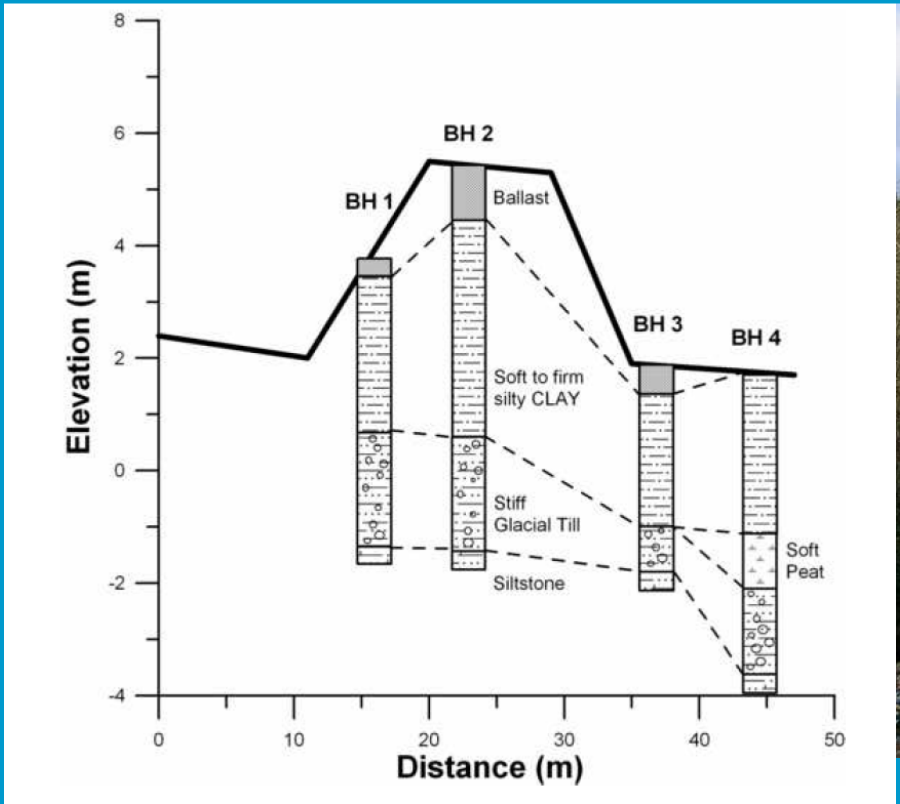
October

- no exceptional storms
- overall rainfall 50% above normal

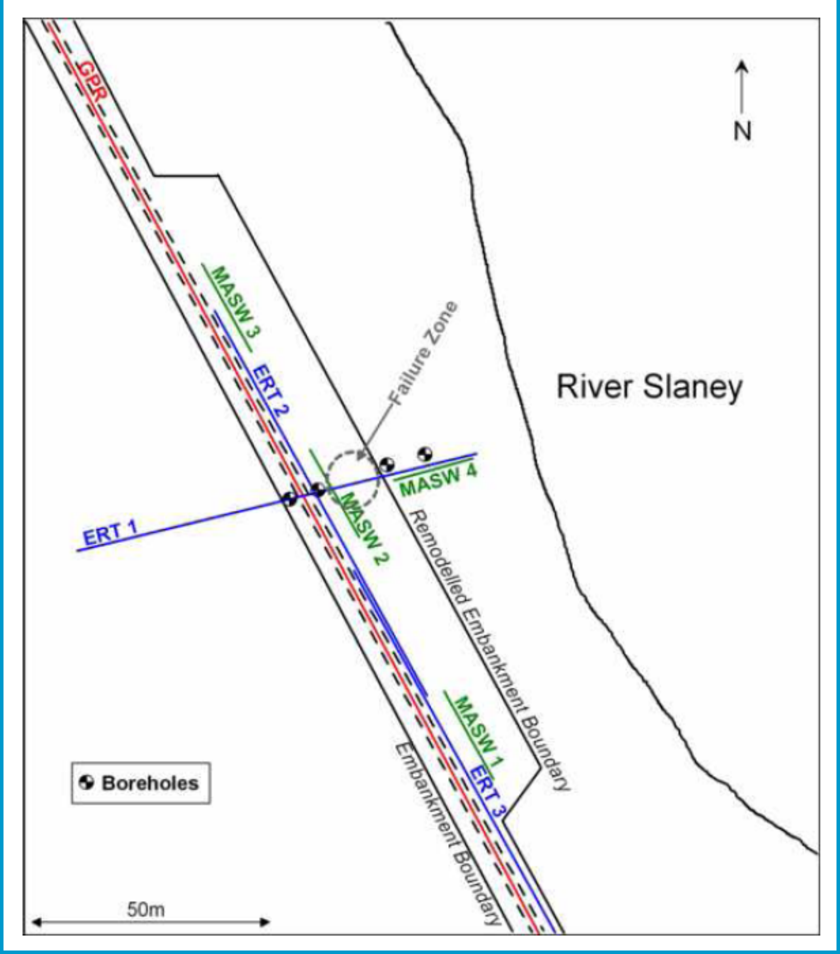
November

- Rainfall 84% above normal
- Included storm on 25th with 58mm of rainfall over 6 hour period.

Cross-Section

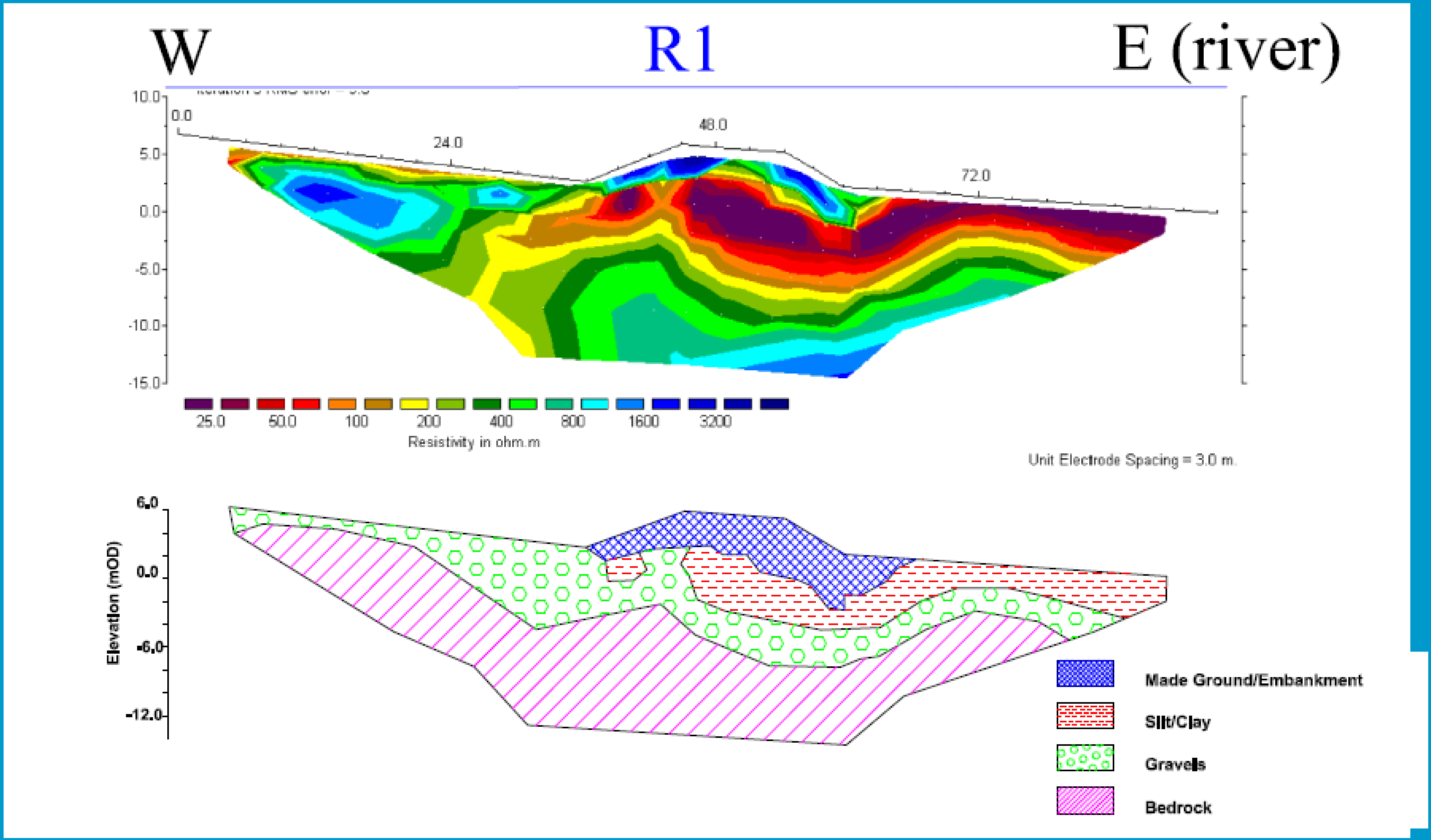


Geophysical Investigation

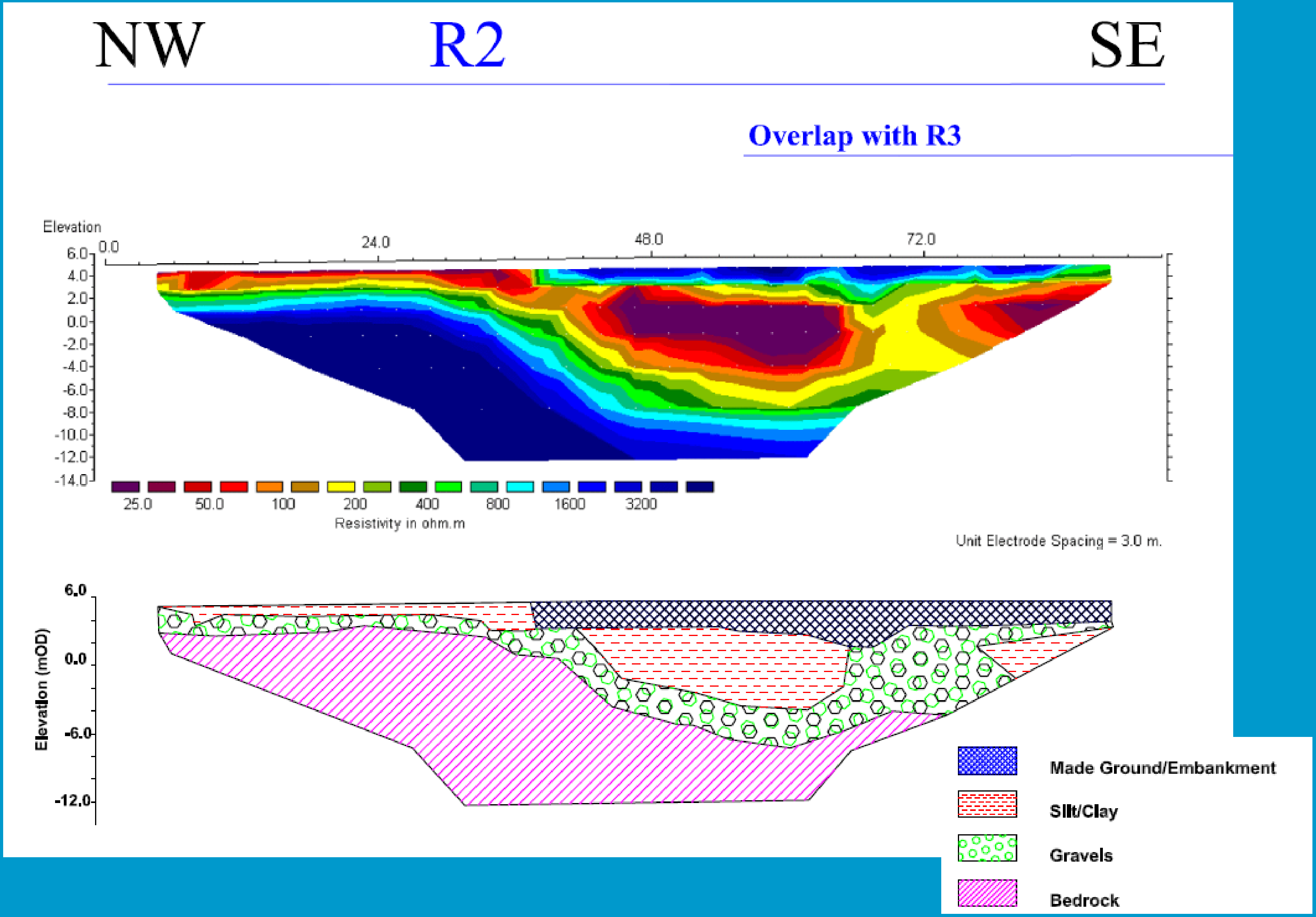


Resistivity investigation across failure plane and along track to confirm soil stratigraphy and investigate suspected lateral flow of water along embankment

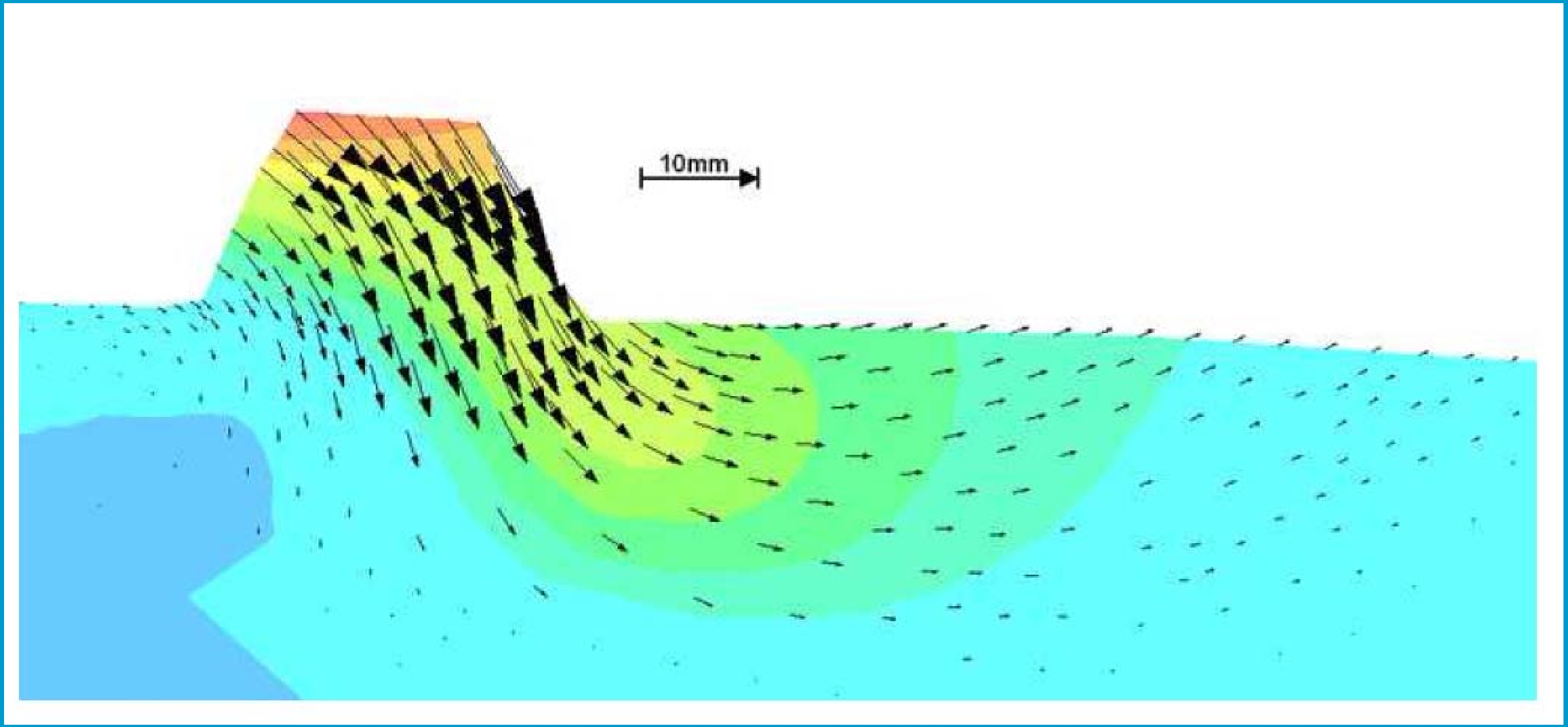
ERT profile across track through failure plane



ERT Profile Along Track

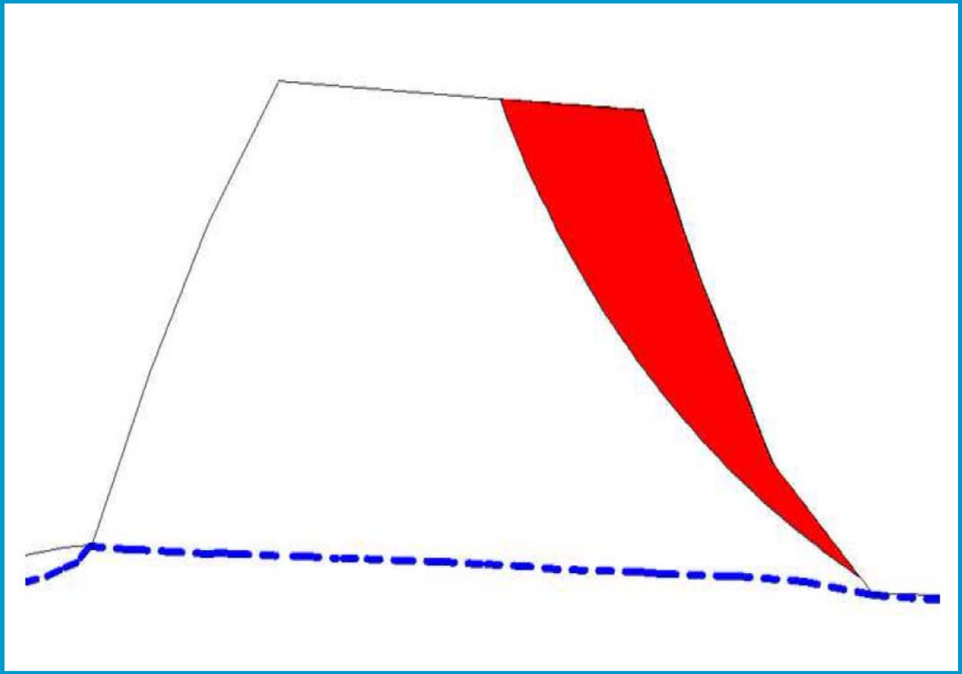


Finite Element Analysis



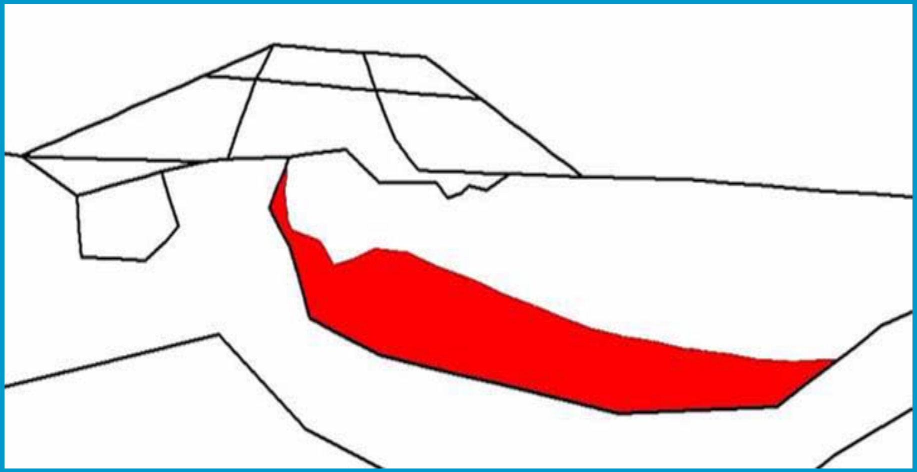
Model of post-construction behaviour

Seepage Analyses



- Rainfall data was used to model infiltration into embankment
- FOS reduced to ≈ 1.2
- Regrading of embankment caused increase in FOS to 1.5

Stress distribution beneath embankment



- Geophysical investigation highlighted extent of soft organic clay present beneath the slope
- Tube samples were obtained as part of a forensic investigation
- Samples exhibited significant creep at stress levels 80 – 100 kPa

Conclusions - Case History

Complex ground conditions. The failure was triggered by heavy antecedent rainfall and the effects were amplified by creep in the soft clay deposit. Geophysics offered key insights for low-cost

Acknowledgements

- Irish Rail who sponsor our work on stability of steep slopes
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