International Perspective of Pipeline Geotechnical Advances and Future Challenges

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Should we change the way we assess some geohazards?

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YES

Let’s start a conversation

Acknowledgements

Doug Dewar – Sr. Engineer,
Pembina Pipelines Corporation, Calgary.

Outline

- Current technologies to identify and measure ground movement of slow, creeping landslides?

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- What do we do about slow, creeping landslides when they are identified?

Key Event to the Formation of IPG

Dosquebradas – December 23, 2011

- 163 mm gasoline/ petrol pipeline.
- Slow creeping landslide movement.
- No physical or visual evidence of ground.

NPS 6 gasoline pipeline rupture: 30+ fatalities.

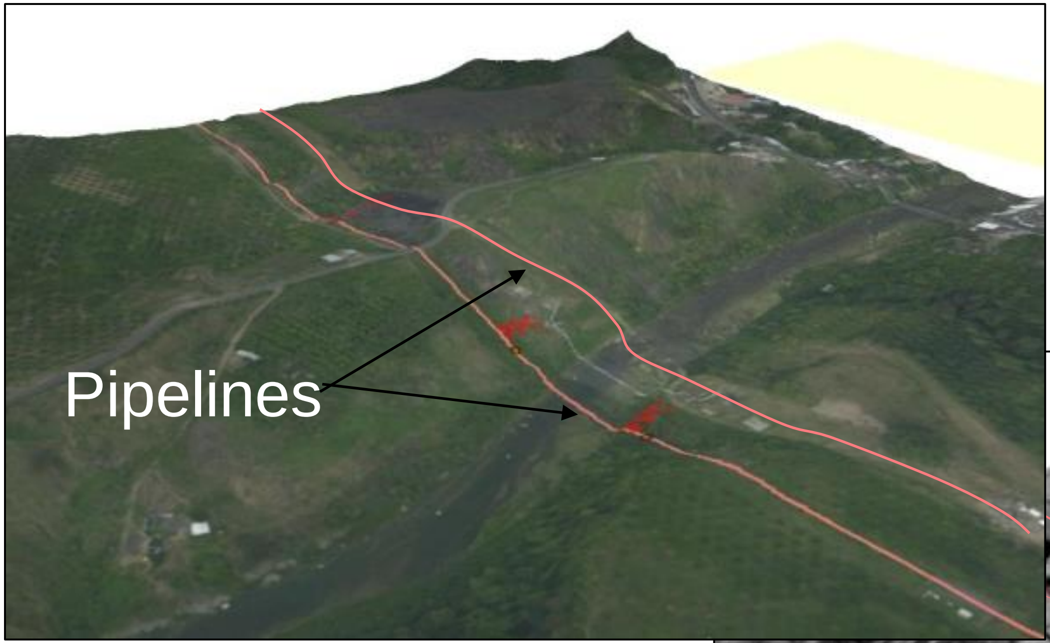
Advances in Geohazard Identification and Best Practices

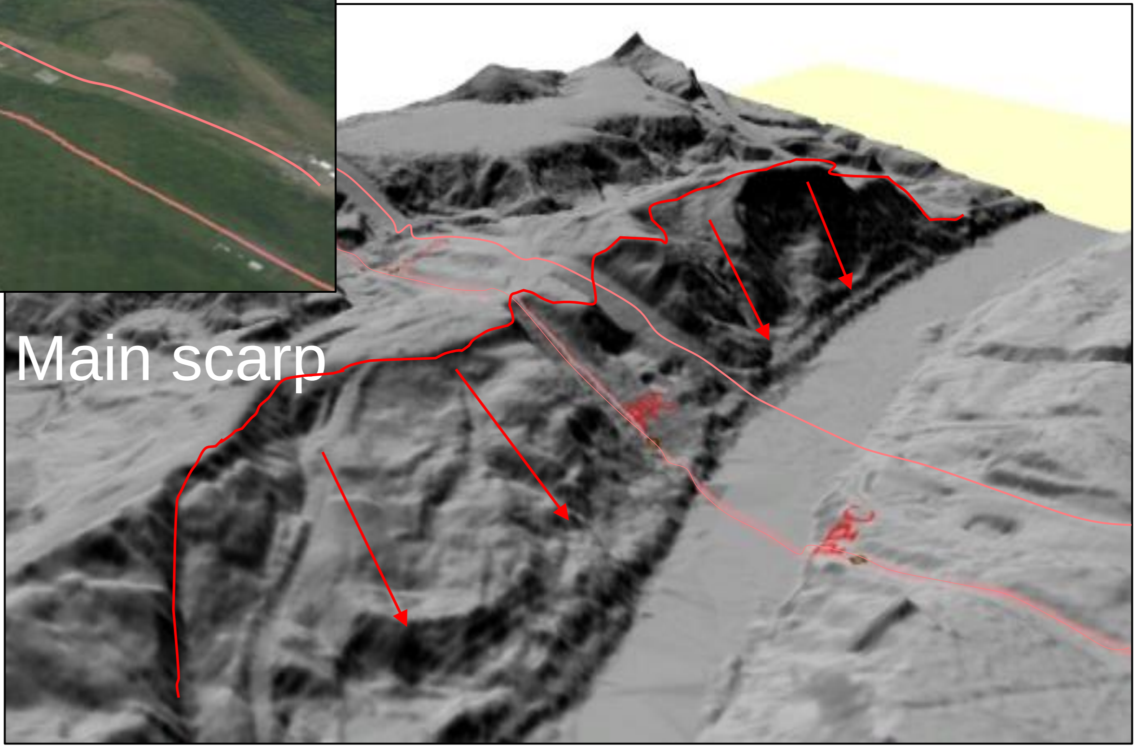
- IGNAA [2020] Guidelines for Management of landslide hazards for pipelines.
- ISO20074 [2019] Petroleum and natural gas industry: Pipeline transportation systems – Geological hazard risk management for onshore pipelines.
- ISO10903 [2024] Petroleum and natural gas industry: Pipeline transportation systems - Pipeline geohazard monitoring technologies, processes and systems.

How to identify strain-inducing landslides?

- Remote sensing – LiDAR, InSAR.
- ILI/IMU.
- Magnetometer tomography surveys.
- GNSS/GPS monuments and surveys.
- Field observations. (Are field teams adequately trained?)

How to identify strain-inducing landslides?





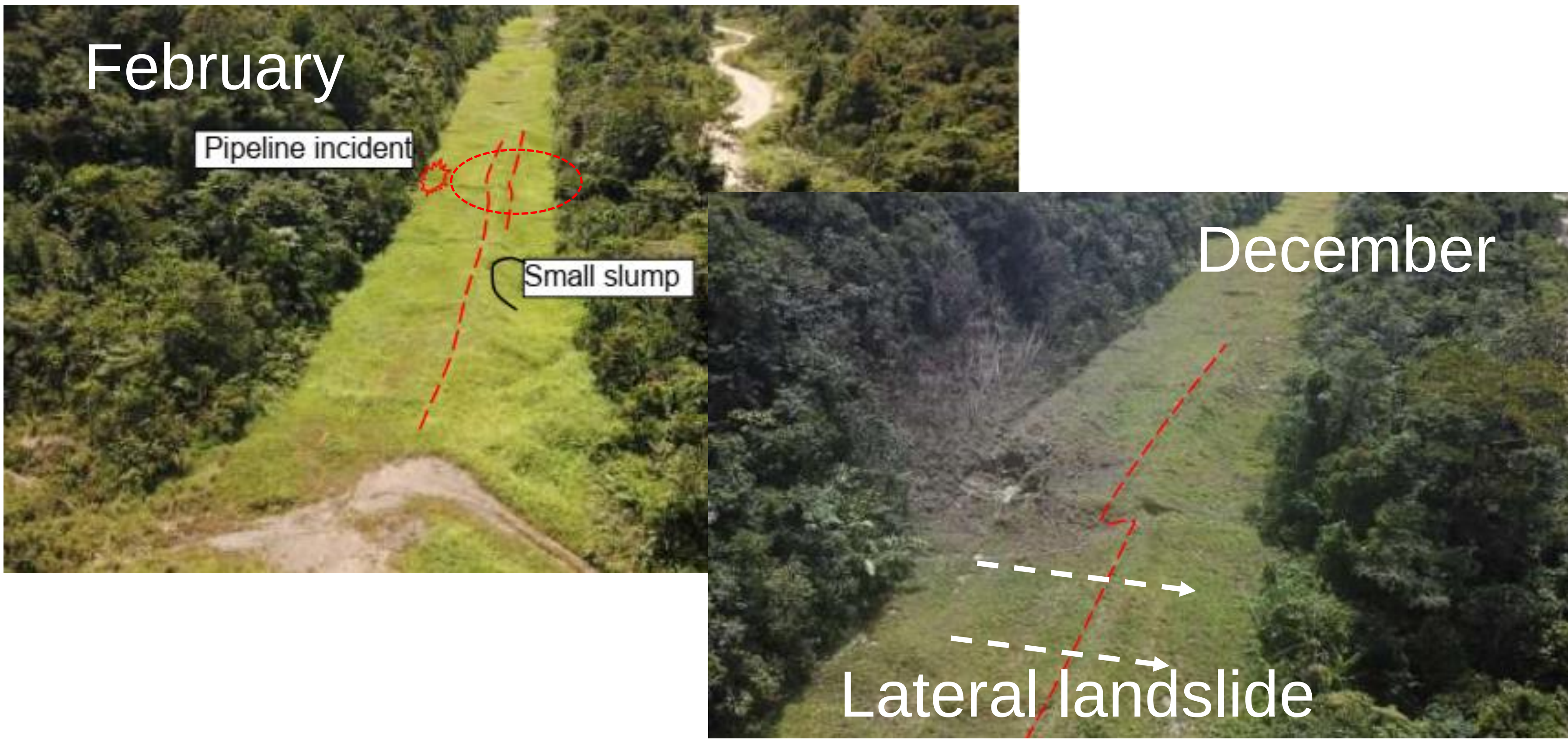
How to identify strain-inducing landslides?

- Aerial or terrestrial magnetometer surveys to determine the lateral displacement of pipelines.

- Maturing technology. Precision to about 0.1 m.
- Well suited to survey limited sections; compare to IMU.

How to identify strain-inducing landslides?

- Aerial drone surveillance/field observations.



Big issues with creeping landslides……

- Why do we assume the landslide will be well behaved in the long-term?

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Big issues with creeping landslides……

- Why do we assume the landslide will be well-behaved in the long-term?
- A well-behaved landslide is well behaved ………. until it isn't.
- Three examples (but there are 1000s more examples!)

Example #1: Kentucky gas pipeline May 2020

Date	Oblique Movement	Activity/observation
2007, 2011, 2017		ILI tool measurement
April 2018	1.2 m	ILI tool measurement
Oct 2018		Site confirmed as geohazard
April 2019		Aerial inspection - erosion noted
June 2019	1.5 m	ILI tool measurement
July 2019		Ground inspection of scarps
Late 2019 – early 2020		Tensile strain capacity versus strain demand assessment
May 2020	2.65 m	Slope failure Loss-of-containment
June 2020		Planned strain relief and strain gauge installation

Example #1: Kentucky gas pipeline May 2020

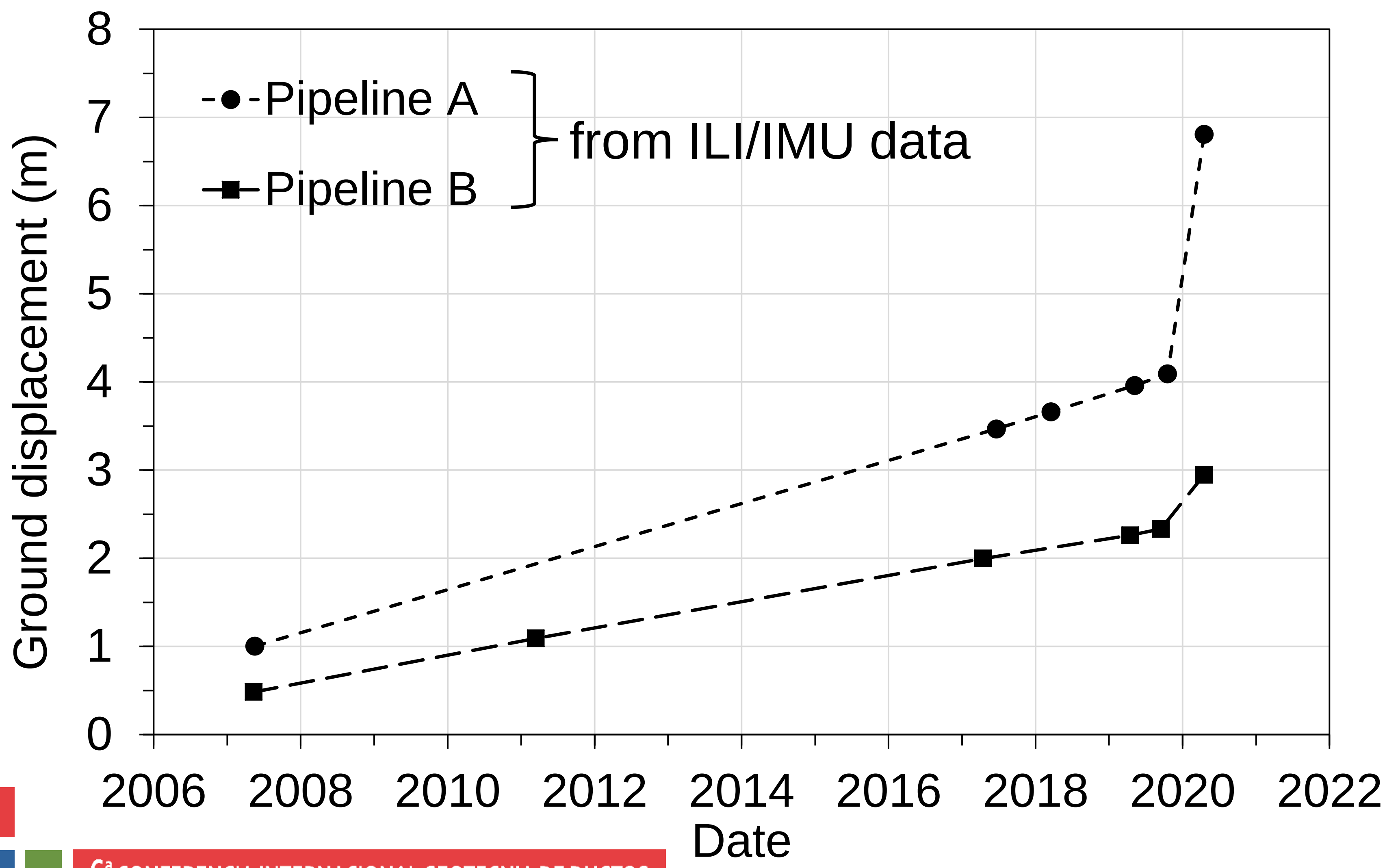

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Photo from NTSB Pipeline Investigation Report: PIR-22/01

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Example #2: China landslide 2020 (Zhang et al. 2021)

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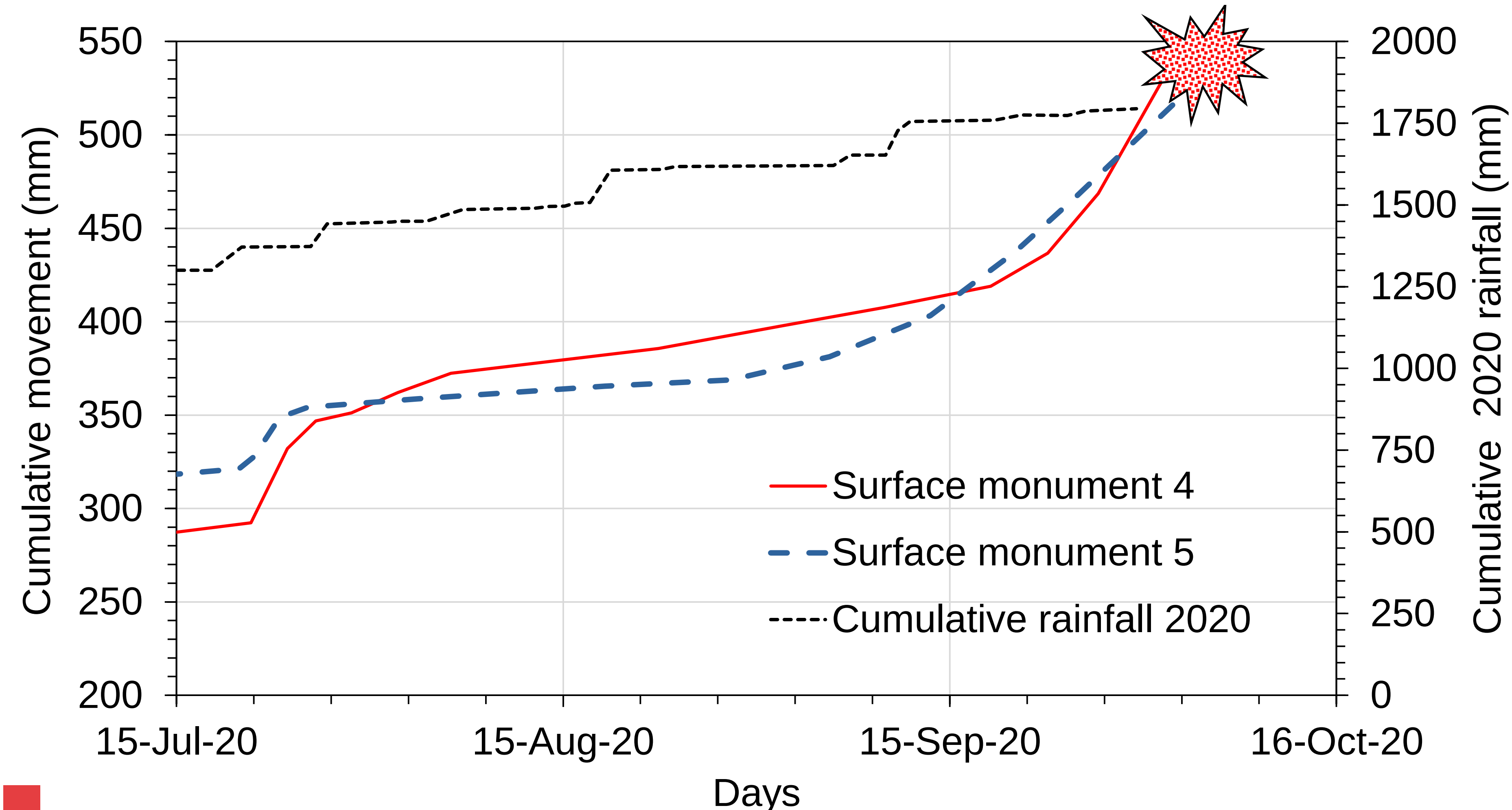
Date	Event/activity
March - April 2020	Construction at toe of slope.
June 2020	Landslide creep; cracks in houses evident.
June 2020	Construction of toe buttress. (But this blocked groundwater drainage from the slope.)
July 2020	Shallow landslides develop. Install surface and deep monitoring.
Late July 2020	Installed culvert under buttress. Cracking intensified.
Sept. 27, 2020	Full landslide failure. No injuries; 72 houses damaged.

Example #2: China landslide 2020 (Zhang et al. 2021)



Example #3: Japan landslide 2004 (Fujisawa et al. 2010)

Date	Event/activity
January 2004	Cracks in retaining wall adjacent to highway near toe of slope.
February 2004	Monitoring and surveillance initiated.
May 2004	20 m wide "surficial soil slip" above retaining wall. Road closed.
June 2004	Typhon #6. Additional rain. Widening of pre-existing cracks in retaining walls. Soil cracks upslope.
August 10, 2004	Full landslide failure.

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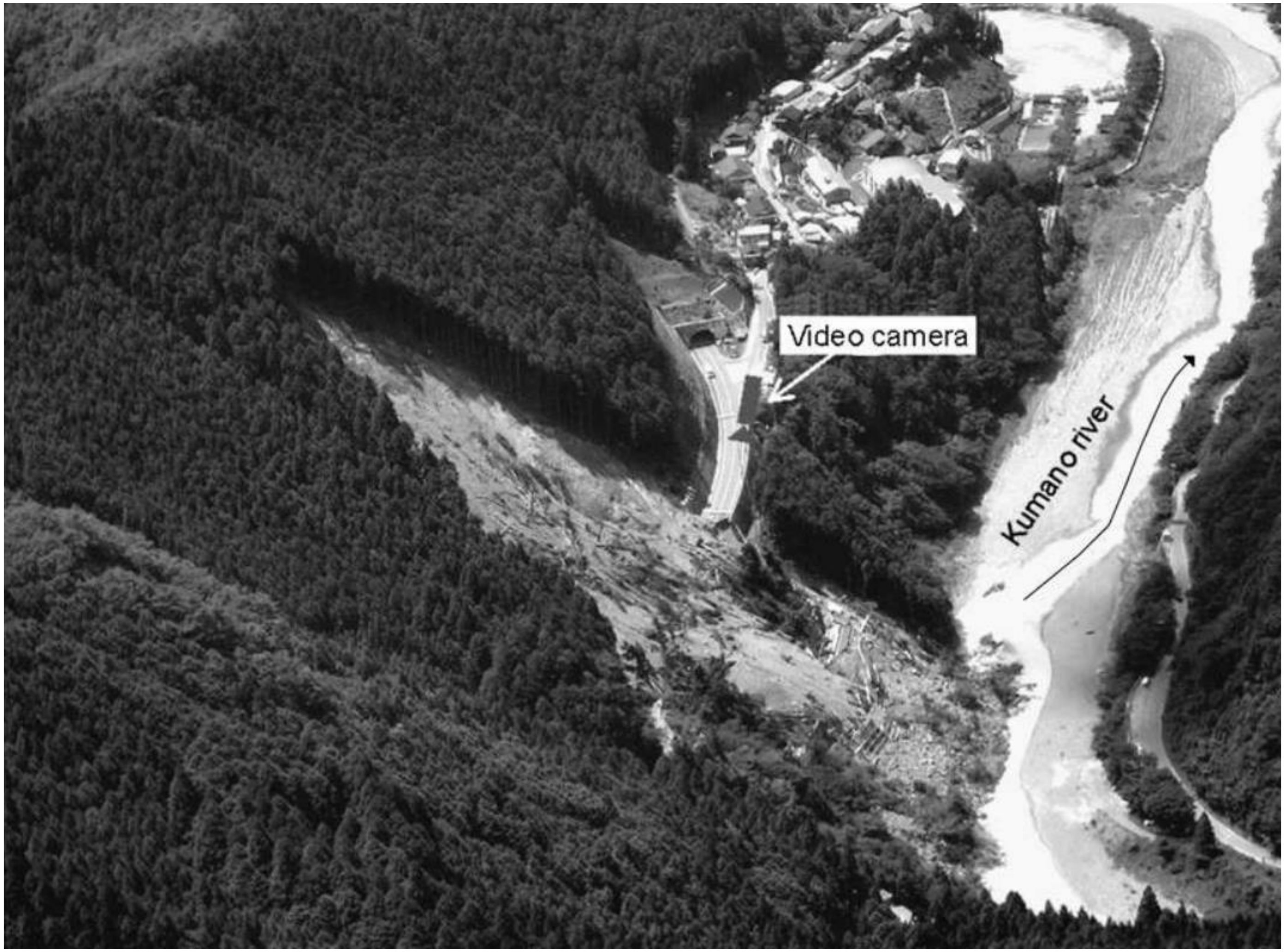

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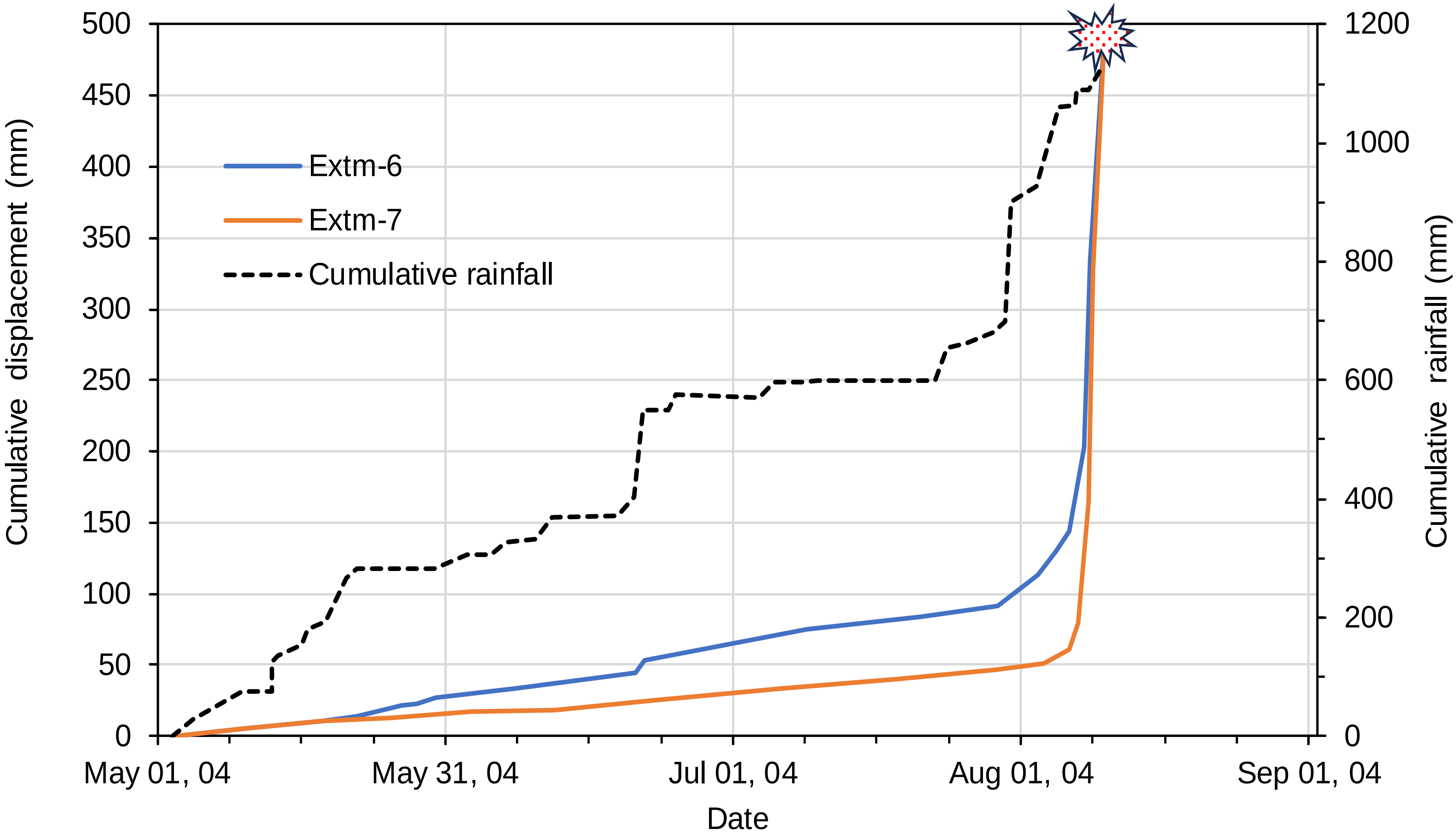
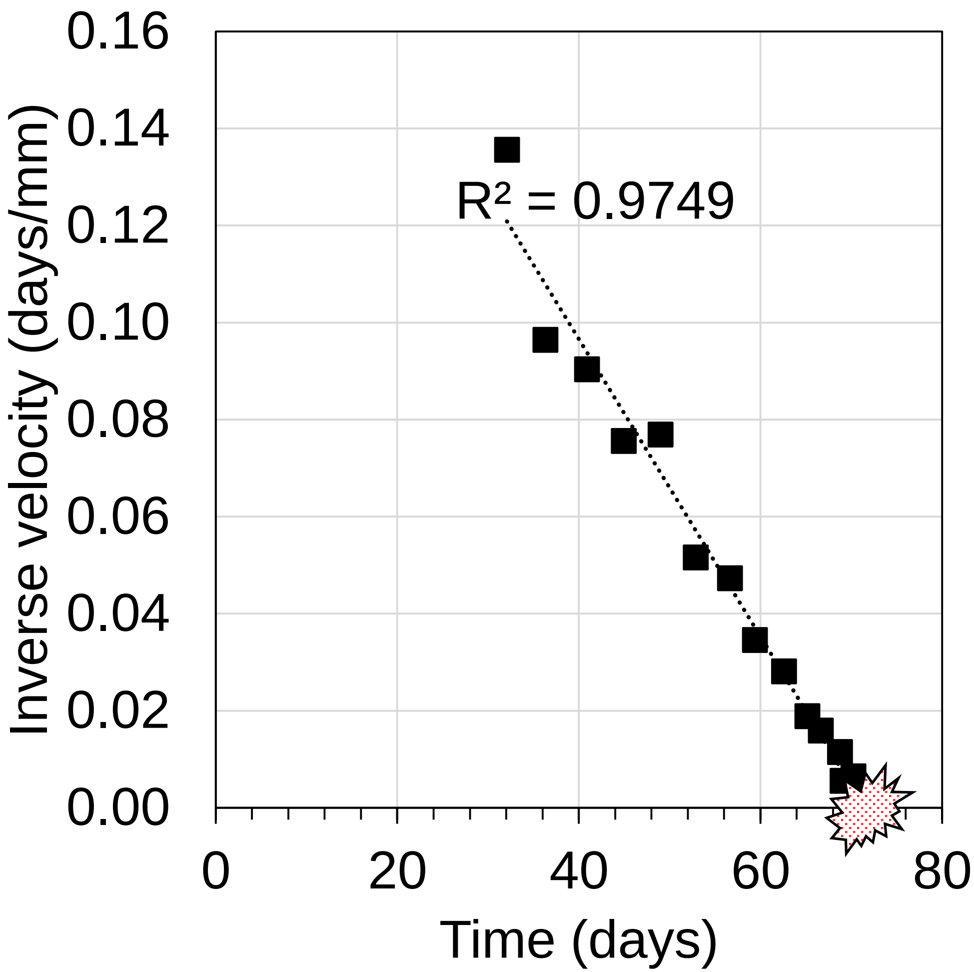


Well-behaved slow creeping landslides – if they stay well-behaved

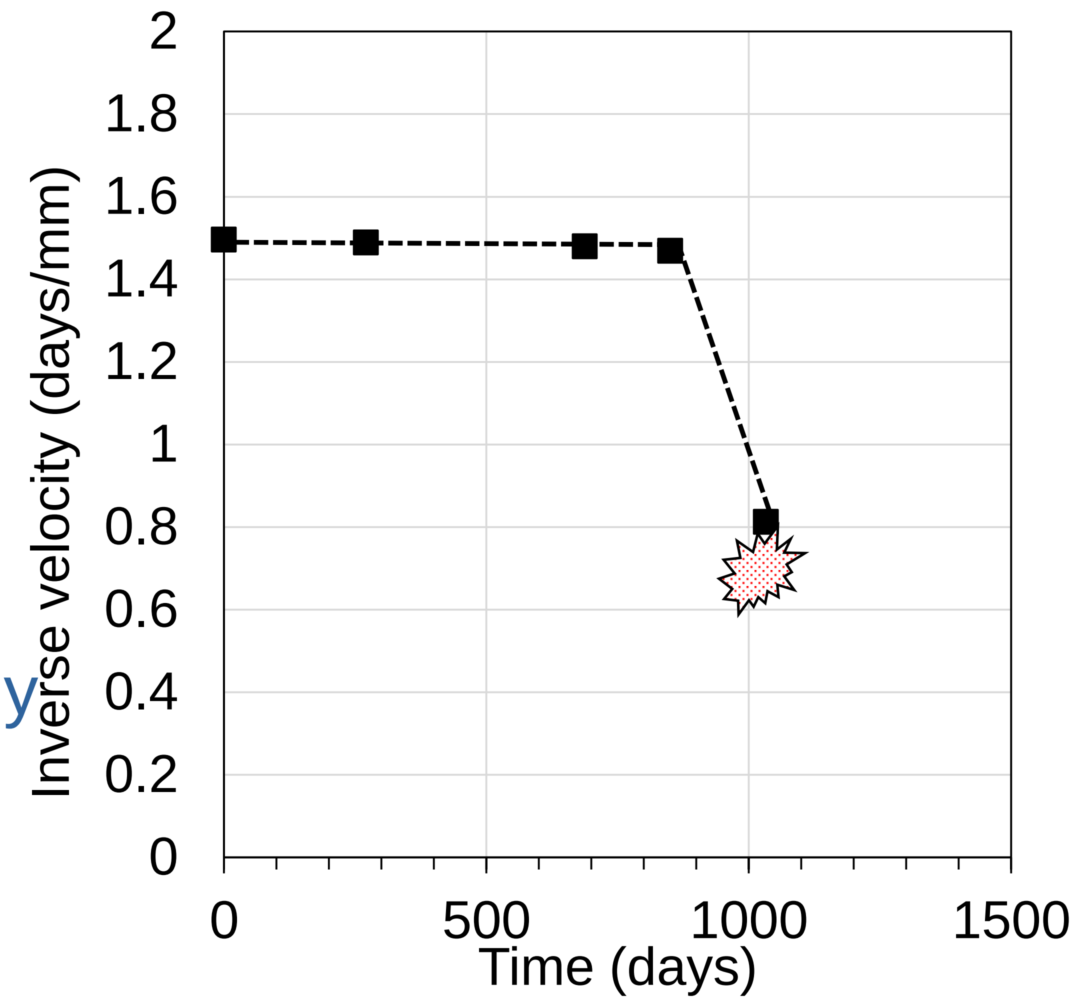
- Predictable creep behaviour.
- Inverse velocity (time/displacement) versus time to predict time to failure.
- See: A. Segalinia, A. Vallettab, A. Carri. 2018. Landslide time-of-failure forecast and alert threshold assessment: a generalized criterion.



Well-behaved slow creeping landslides??

- Example #1 Kentucky pipeline.
- Based on ILI data.
- Using inverse velocity (time/displacement) versus time to predict time to failure.

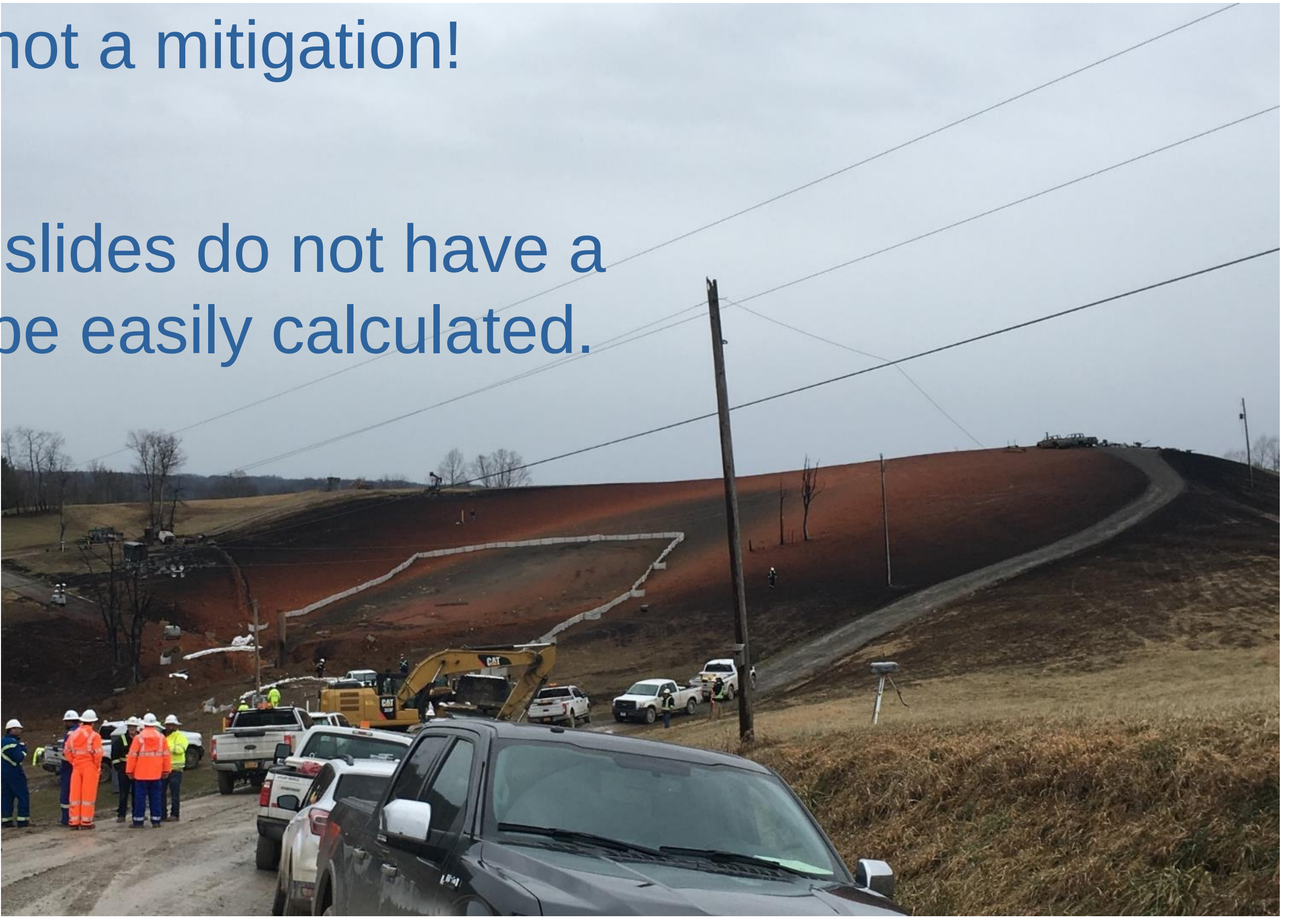
- How can we reasonably predict time of failure?



Lessons learned from slow (creeping) landslides

- Monitoring is not a mitigation!

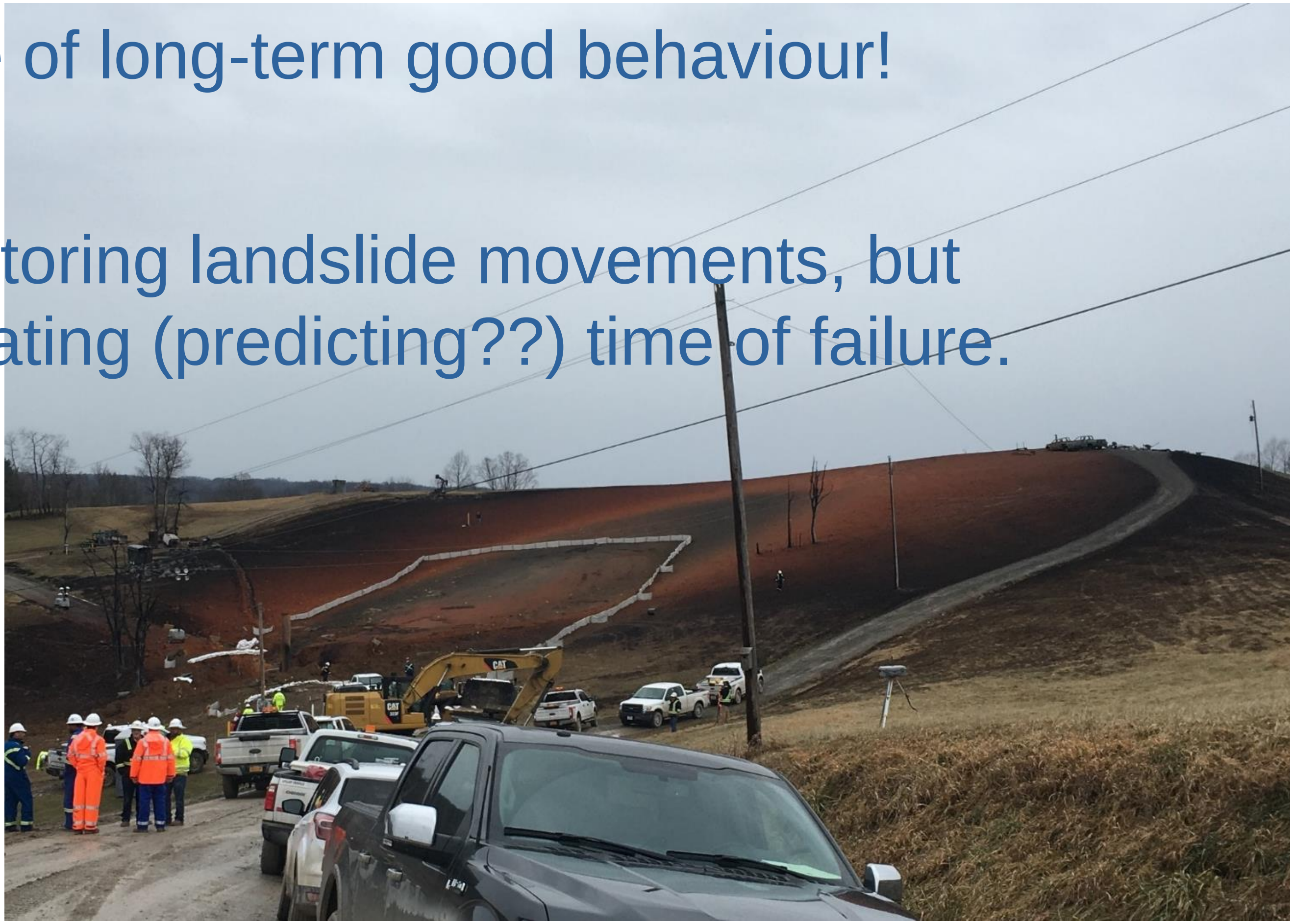
- Creeping landslides do not have a FoS that can be easily calculated.



Lessons learned from slow (creeping) landslides

- No guarantee of long-term good behaviour!

- Good at monitoring landslide movements, but poor at estimating (predicting??) time of failure.



Lessons learned from slow (creeping) landslides

- From good to bad landslide behaviour is often associated with rainfall events.

- But, forecasting high rainfall events with sufficient lead-time to initiation mitigation is often not possible.

Lessons learned from slow (creeping) landslides

- Accurate strain capacity estimates of (older) pipelines is questionable.

- Beware - Tolerating a degraded state of landslide stability leads to normalization of the status quo.

Lessons learned from slow (creeping) landslides

- Beware of conformation bias. (Reject data that does not support our preconceived theory).

- Over confidence and complacency are both dangerous.

Lessons learned from slow (creeping) landslides

- Risk-based decision making should not be applied to creeping landslides (and perhaps other geohazards, e.g., rockfalls, outburst floods).

Are all landslide failures black swan events????

- Hayes, J. and Hopkins, A. 2018. *Nightmare pipeline failures: Fantasy planning, black swans and integrity management.*

- Black swans – events so rare that no one can predict their occurrence.

Are landslide failures black swan events????

- Hayes, J. and Hopkins, A. 2018. *Nightmare pipeline failures: Fantasy planning, black swans and integrity management.*
  - Read this book!!!!!!
- Black swans – events so rare that no one can predict their occurrence.

- Most pipeline-geohazard interactions are **not** black swan events.

Are landslide failures black swan events????

- North America - 0.02 failures/1000 km/year
- Western Europe - 0.02 failures/1000 km/year
- Brazil - 0.07 failures/1000 km/year
- Bolivia - 0.5 failures/1000 km/year

Are landslide failures black swan events????

- North America - 0.02 failures/1000 km/year
- Western Europe - 0.02 failures/1000 km/year
- Brazil - 0.07 failures/1000 km/year
- Bolivia - 0.5 failures/1000 km/year
- Pipeline S.E. Asia - 1.5 failures/1000 km/year!!!

How Do We Improve Our Response to Impredictable (not unpredictable) Geohazards?

- Apply precautionary principle.

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- Apply consequence-based decision making not risk-based decision making.

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- Apply precautionary principle.
- Apply consequence-based decision making rather than risk-based decision making.

- Apply principles of high reliability organizations.

How Do We Improve Our Response to Impredictable (not unpredictable) Geohazards?

- Precautionary principle:

  Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

  (from U.N. Principle 15 of the Rio Declaration on Environment and Development.)

How Do We Improve Our Response to Impredictable (not unpredictable) Geohazards?

As it applies to creeping landslides……

In the absence of <u>very compelling</u> evidence of ongoing stability, assume imminent instability.

How Do We Improve Our Response to Impredictable (not unpredictable) Geohazards?

- Risk-based decision making:

  Risk = Probability x Consequence

- But how do we estimate probability of failure of a creeping slope, or other geohazards that may accelerate to failure without warning?

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- Consequence-decision making:
  - Ignores likelihood and time to failure.
  - It is consistent with processes of high-reliability organizations.

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- Consequence-decision making:
  - Ignores likelihood and time to failure.
  - Consistent with processes of high-reliability organizations.
  - Allows for priority-setting based on consequence of pipeline failure.
  - The cost of repair/stabilization is often much lower than the cost of clean-up.
  - *If it's broke – fix it.*

How Do We Improve Our Response to Impredictable (not unpredictable) Geohazards?

- Consequence-decision making: what is the definition of "consequence"? This will help set priorities.
  - In risk-based decision making it is usually "loss-of-containment".
  - In consequence-based decision making we can perhaps use a broader, more open definition:
    - Loss-of-containment ,,, yes… but
    - Cost of clean up
    - Environmental cost
    - Revenue loss etc.

How Do We Improve Our Response to Impredictable (not unpredictable) Geohazards?

Location	Date	Product	Impacts and approx. costs ($US)
Near Peace River Alberta	2011	Crude oil	$11 million+ in cleanup costs
Yellowstone River, Montana (vortex shedding)	2011	Crude oil	$165 million in cleanup costs
Red Deer River, Alberta	2012	Crude oil	$53 million+ in cleanup costs
North Saskatchewan River (earth movement)	2016	Crude oil	$107 million in cleanup costs
Noble County, Ohio (earth movement)	2018	Natural gas	$5.2 million in cleanup costs $20 million per day lost income
Nixon Ridge, West Virginia (earth movement)	2018	Natural gas	$13 million
Noble County, Ohio (earth movement)	2019	Natural gas	Several injuries, two residences destroyed: cleanup costs unknown

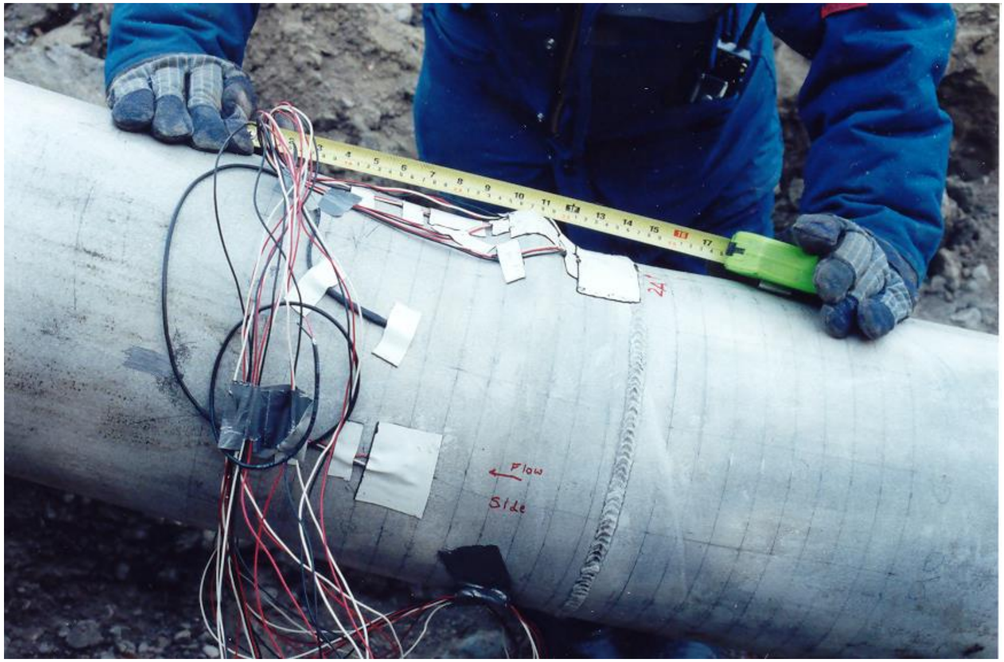
Attributes of High Reliability Organizations

- Have geo-professionals on staff or on retainer, dedicated to managing geohazard threats to the assets.
- Ensure the organization has a well developed an up-to date GHMP in-place. Use it!

Attributes of High Reliability Organizations

- Use multiple sources of data collection and monitoring: LiDAR, InSAR, SIs, IMU/ Geometry tool, surface/aerial monitoring, field observations and reconnaissance.

- Examine all data (be skeptical). Assume the worst.



Attributes of High Reliability Organizations

- Ensure adequate funding for both integrity management and repair. Consequence-based decisions need to be acted on with urgency, not postponed due to budget constraints *(Pay now or pay more later!!).*

- Train field staff in geohazard identification. Ensure field staff are observant on and off the right-of-way. *(Why is that fence leaning over? Why is there a new crack in the road asphalt?)*

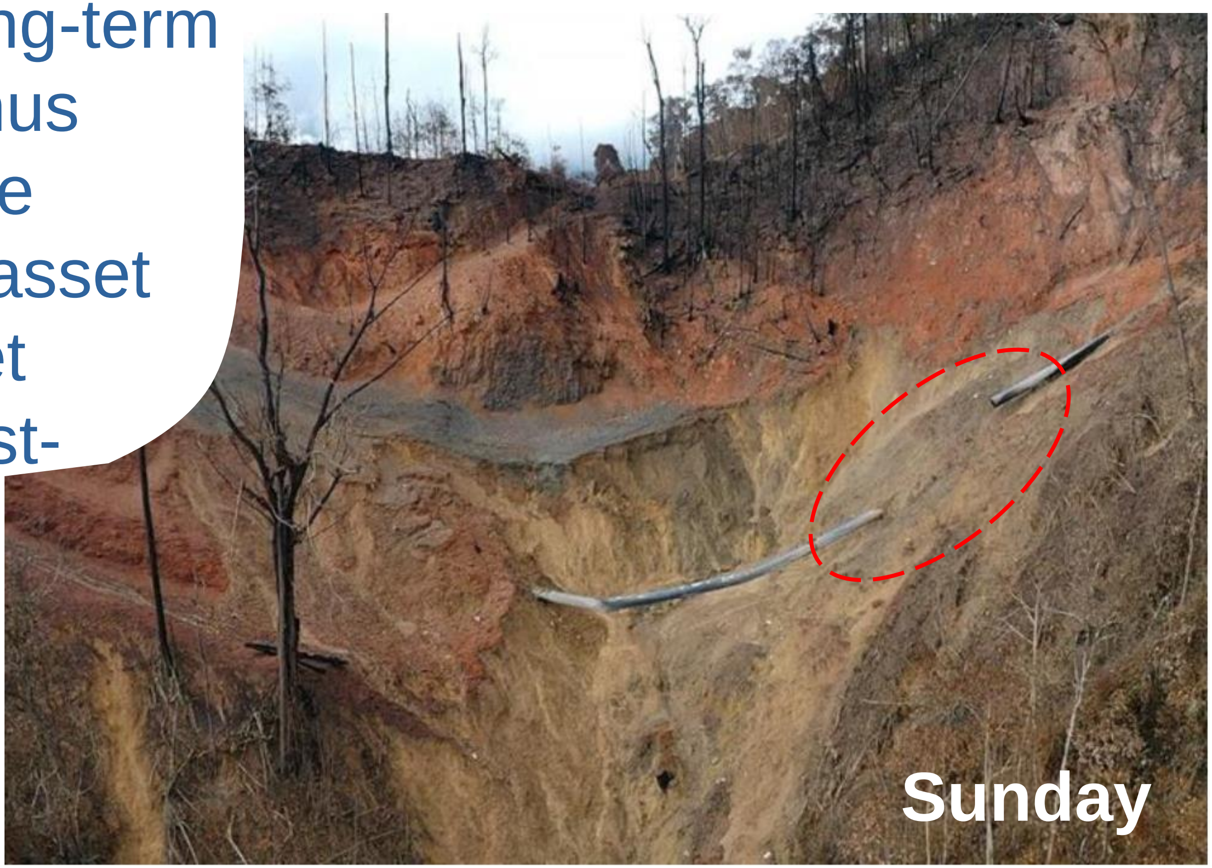
Attributes of High Reliability Organizations

- Ensure company culture encourages incident reporting and inter-disciplinary communication.

  (Can the field team call their supervisor at 8 PM on a Saturday evening?)

Attributes of High Reliability Organizations

- Company management should focus on long-term asset integrity. Bonus programs should be structured around asset integrity, not budget performance or cost-saving.



Benefits of HROs and Consequence-based decisions

- Lower ultimate costs.
- Better stakeholder relations.
- Improved asset integrity.
- Improved reliability.
- Integrity team sleeps well at night.

Final Thoughts

- Geo-professionals are very good at what they do. Since the 1980s there has been a constant and steady decline in the number of geohazard-related pipeline incidents.

(from Sweeney, 2017)

Geotechnical input	Failure rate
Historical practice	2.11 per 1000
Historical practice with minor input	0.56 km per
Modern practice with moderate input	0.17 year
Modern practice with SME input at all stages	≈ 0

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- Risk-based decision making served us well since the 1990s; but….
- Our climate is changing; frequency and severity of rain events may be changing.

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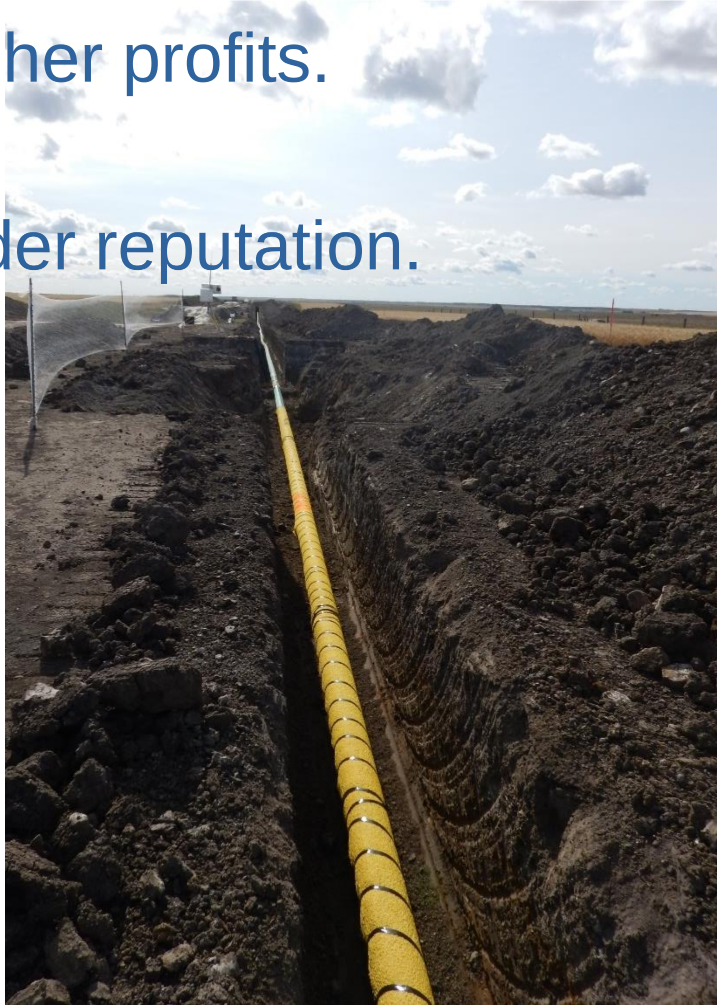
- Risk-based decision making served us well since the 1990s; but….
- Our climate is changing; frequency and severity of rain events may be changing.

- Creeping landslides are not amenable to FoS calculations by limiting equilibrium methods.

- Creeping landslides may be well-behaved for a long time before suddenly accelerating with little warning.

Final Thoughts

- Benefits to pipeline operators
  - Lower long-term costs and higher profits.
  - Improved public and stakeholder reputation.



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- Benefits to pipeline operators
  - Lower long-term costs and higher profits.
  - Improved public and stakeholder reputation.
  - More consistent throughput and service.
  - Less stress on employees.

Final Thoughts

Do these operators wish they had acted sooner?

Let’s start a conversation.
Mucho gracias. Thank you.