Understanding Large Standoff Magnetometry (LSM) for Proper Field Deployment

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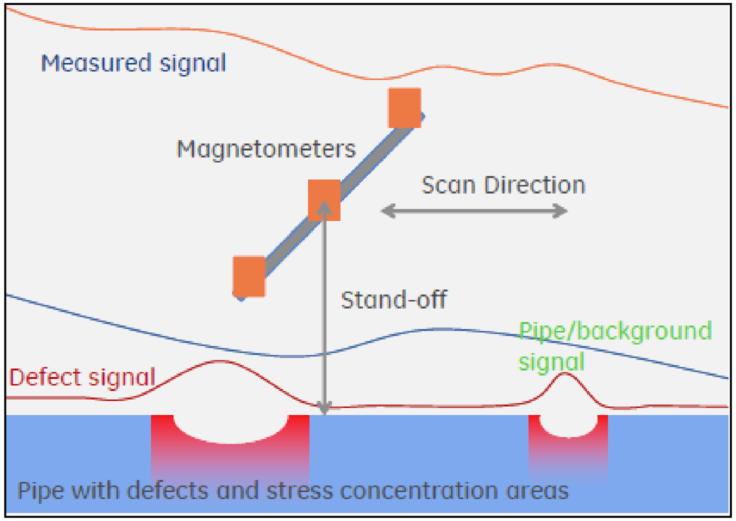
Together, Building a Better California

Contents

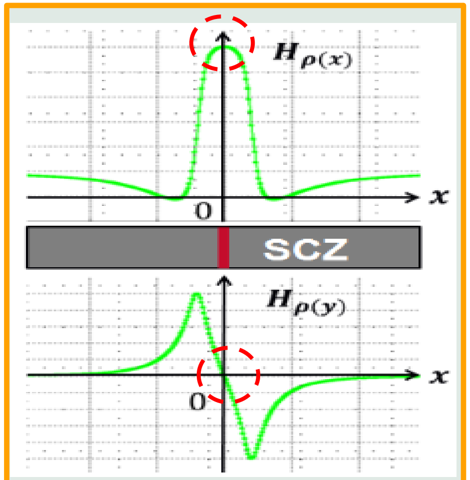
- Introduction of Large Standoff Magnetometry (LSM)
- Challenges in adopting this new inspection technology
- PG&E's Approach and Efforts
- Recommendations for next steps

Large Standoff Magnetometry (LSM)

- Based on stress-magnetization mechanism
- A non-invasive, above-ground, passive surveying technology to detect anomalies/features and evaluate stress concentration of ferromagnetic materials in earth magnetic field
- A screening tool to complement ILI and DA/IIT program



M. Navalgund, et al., "LSM for Pipeline Inspection", 2016

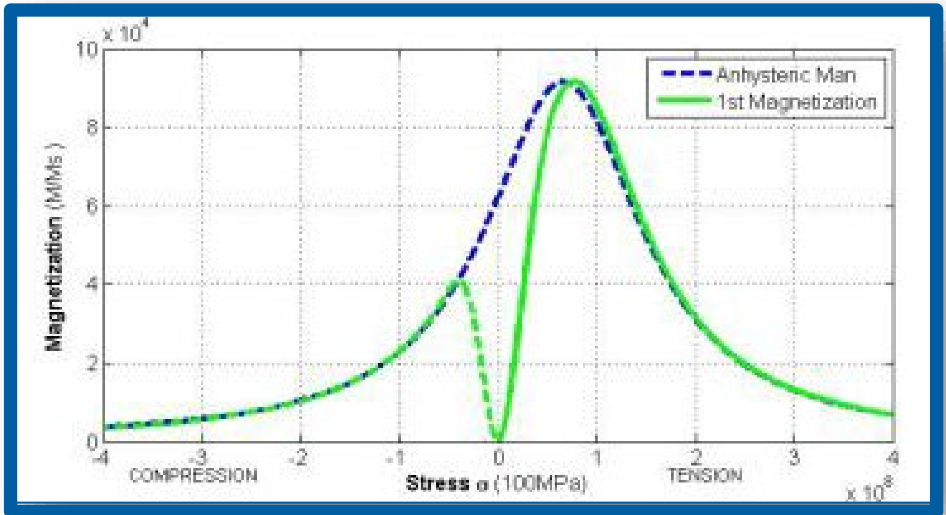


Characteristic SMFL curves

Wang, Z.D., et al., NDT & E International, 2010. 43(6): p513-518

Magnetomechanical Modeling: Quantification

- Modeling Elastic Stress-Magnetization in carbon steel



$$\frac{dM}{d\sigma} = \frac{1}{\epsilon^2}(\sigma \pm \eta E)(1-c)(M_{an} - M_{irr}) + c\frac{dM_{an}}{d\sigma}$$

D. C. Jiles and L. Li, "Modified law of Approach for Magnetomechanical Model -Application of Rayleigh Law to Stress." *IEEE Transaction on Magnetics* Vol. 39 N0.5 (2003): pp.3037.

M: magnetization; σ : stress; ϵ: strain; E: material Young's modulus

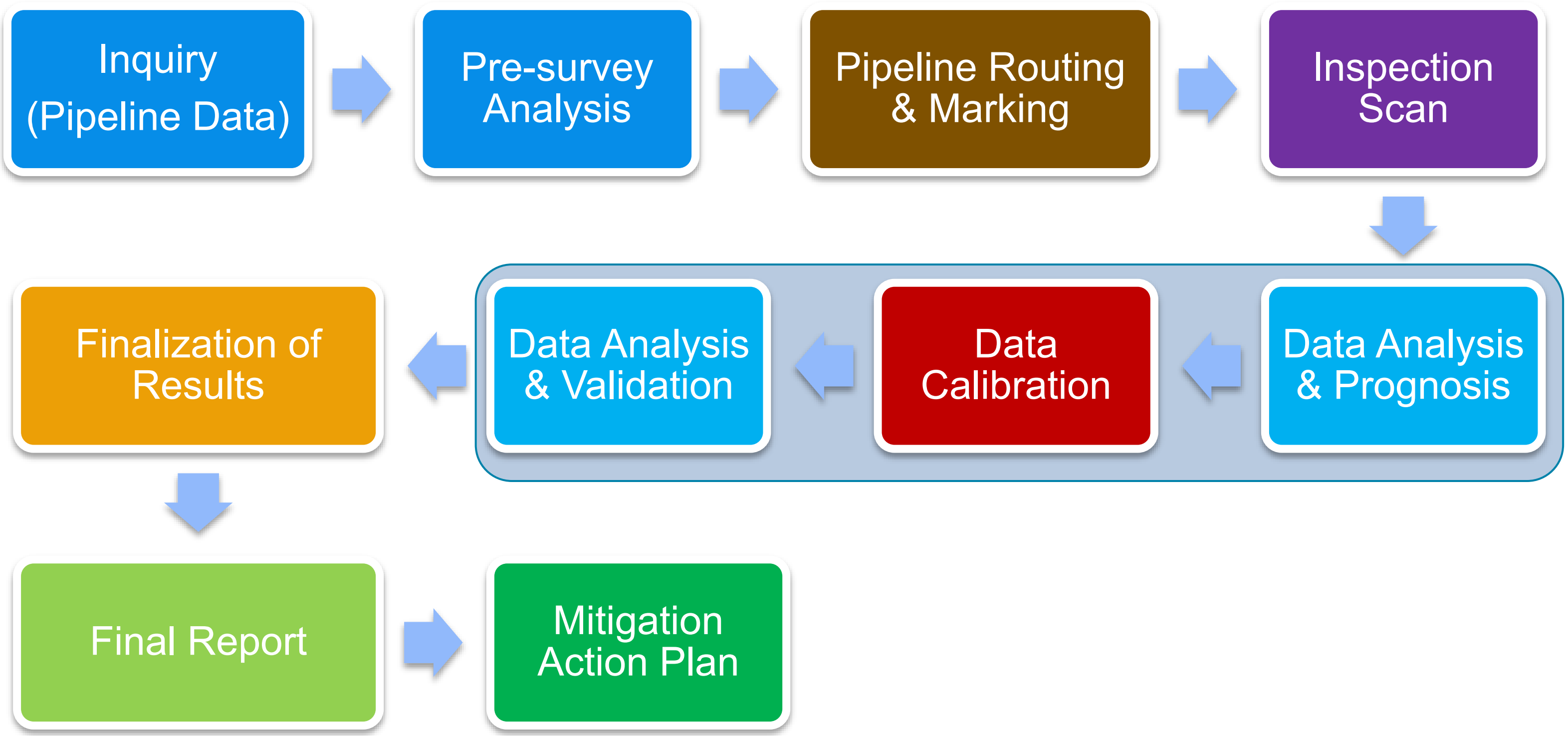
η and c: constants (ability of magnetic domains to be magnetized)

M_{an} : anhysteric magnetization

M_{irr} : irreversible part of magnetization

- No established model yet for Plastic Stress-Magnetization

Process Flow of LSM Field Survey



LSM Instrumentation

- Non-Contact Magnetic Scanners
- Carrier platforms
- GNSS/GPS systems
- Data acquisition/processing/analysis

LSM-on-Drone

Mobile GPS Rover on Cart

Mobile Rover and Portable GNSS base station for real-time correction

Standalone GPS Rover with thread-chain odometer

Mobile GPS Rover in backpack and real-time correction through base station network

Major Benefits

- Reporting **anomalies in any orientation causing stress-magnetization** in the pipeline wall
- Suitable for **unpiggable or difficult-to-inspect pipelines**
- **Compliment to the current ILI and DA/IIT practices**
- **3D Mapping of pipeline route by some vendors**
- **The only known technology so far that can be mounted on UAV for direct pipeline scan**
- **No pre-inspection preparation** of the pipeline or modification to operating parameters
- **No interruption to pipeline operations**
- **Easy-operation and high-efficiency**
- **Low-cost hardware**

Major Limitations of LSM

- **Environmental limitations**
- **Technical limitations**
  - Background magnetic signatures and nearby sources of magnetic interference
  - Stress is not the only effect and non-linear magnetization in nature
  - Pre-locating/marking pipeline
  - GPS/GNSS systems and positioning correction
  - Maximum standoff distance, minimum pipeline diameter and wall thickness
  - Pipeline's residual magnetization and operation pressure
  - On-site calibration ?
  - Qualitative assessment
  - Anomaly or feature type identification

History & Current Status of LSM

- Introduced into the international market --- Middle 2000s
- Evaluation at Industry Consortia (NYSEARCH, PRCI)
- Efforts at Operators
- LSM vendors
- Academic or Government Research Community

Issues and Challenges for Field Deployment

- Still quite some inconsistent performance after many years of commercial trials
- Most evaluation efforts so far are large-scale field trials focusing on POD and POI data
- Lack of clear understanding of fundamental physics
- Limited knowledge and information sharing
- Exaggeration of the existing LSM's capability by some vendors
- Unrealistic expectation or lack of confidence by operators/end users
- High price of commercial field trials and fundamental studies
- Lack of government R&D funding support
- Lack of guidance for deployment
- Regulatory acceptance in the future ???

Small-Scale Field Trials at PG&E

Main Objectives

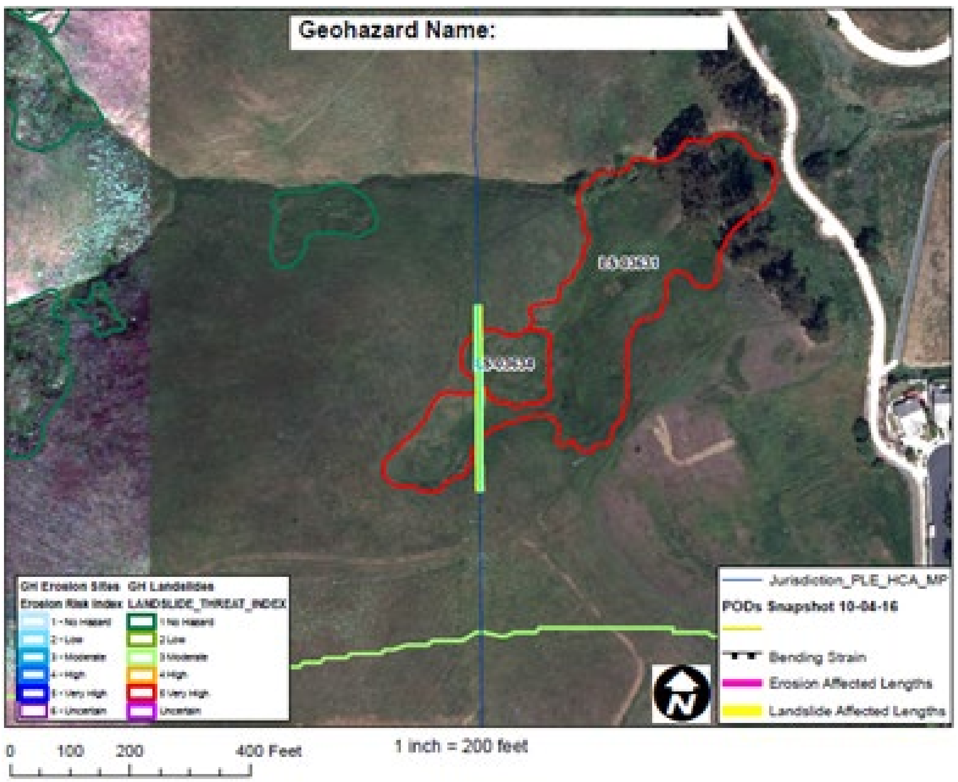
- To evaluate qualitative capability and limitation of detecting anomalies associated with easily identified elevated stress
- To understand quantitative estimation of elevated stress
- To evaluate quantitative locating accuracy on pipeline reference features
- To observe overall field operation, assess technology readiness level and potential issues for field deployment in the future
- To define strategy going forward

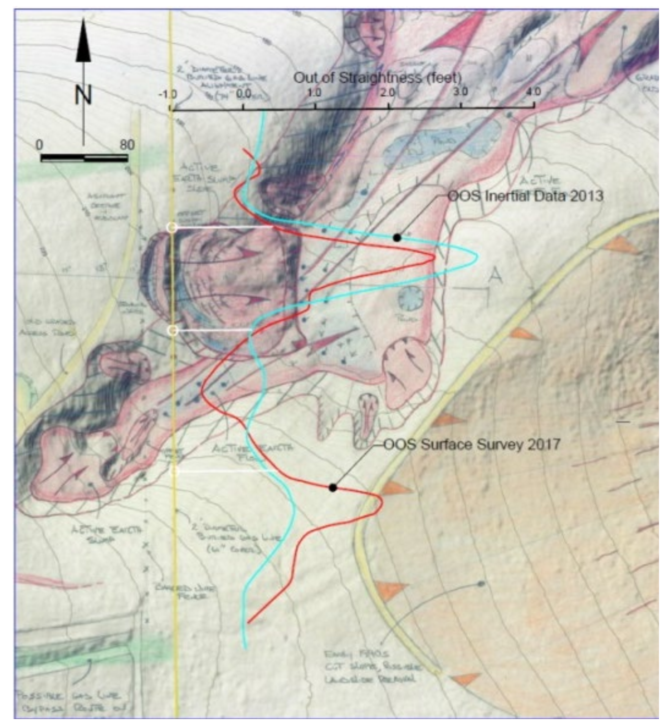
Evaluation Approach

- **Selection of LSM Vendors**
  - Three well-known active vendors.
- **Selection of Field Sites**
  - A range of typical field environment
    - Industry-residence mixed suburb area with minor electromagnetic interference
    - Open space suburban area
    - Open space hilly area
    - Open space hilly area with landslide
  - Availability of pipeline reference data
    - Excavation prior to or after LSM trial
    - ILI data with excavation correction
    - ILI data without excavation
    - Geohazard survey data prior to LSM trial
  - Schedule, Resource and Budget

Case Study: Locating Peak Strain at a Landslide

- **Geohazard Survey**
  - Landslide hazard with affected length of 132 ft
  - <u>Hazard Risk Index 5 – very high</u>

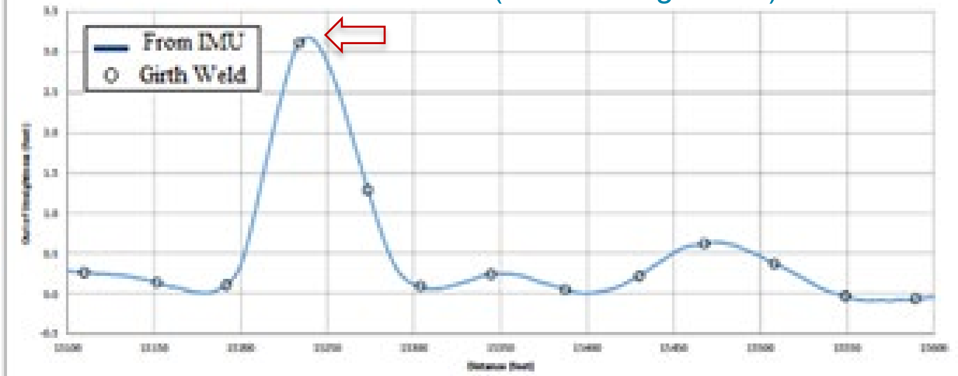




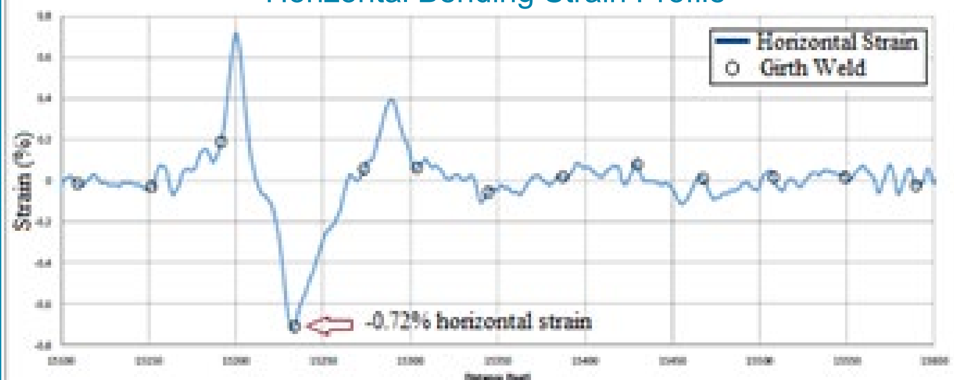
ILI IMU data and strain-stress analysis

- ILI IMU: “W shape” horizontal bending strain profile with a peak of 0.72%
- Well-defined geometry signatures characteristic of a landslide
- Peak strain located at girth weld
- <u>Beyond yielding</u>

Horizontal OOS (out-of-straightness)



Horizontal Bending Strain Profile



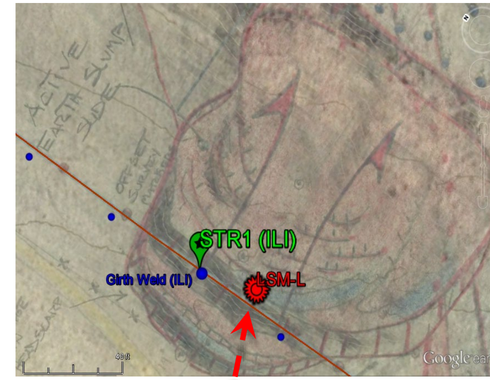
The cut-off

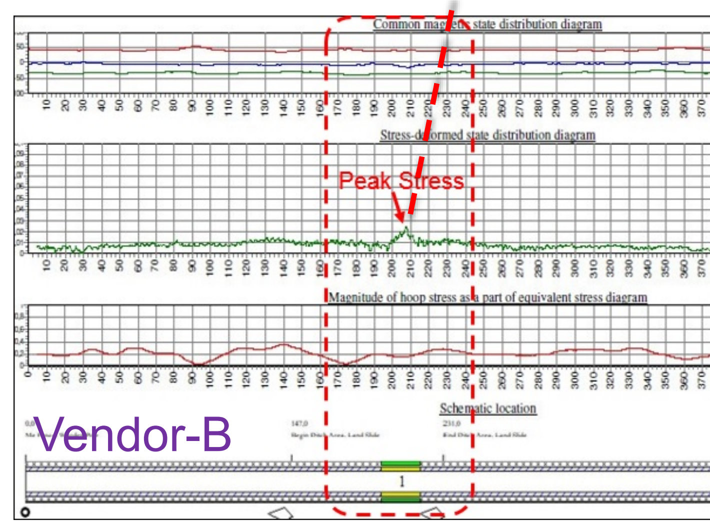
LSM Survey Outcomes

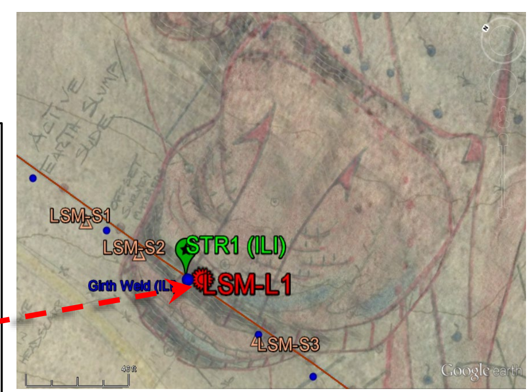
- Large magnetic profile signature
- Large locating errors (10-26 ft)
- Medium-High risk ranking
- Identification (impact of external force in axial direction) reported by Vendor-B

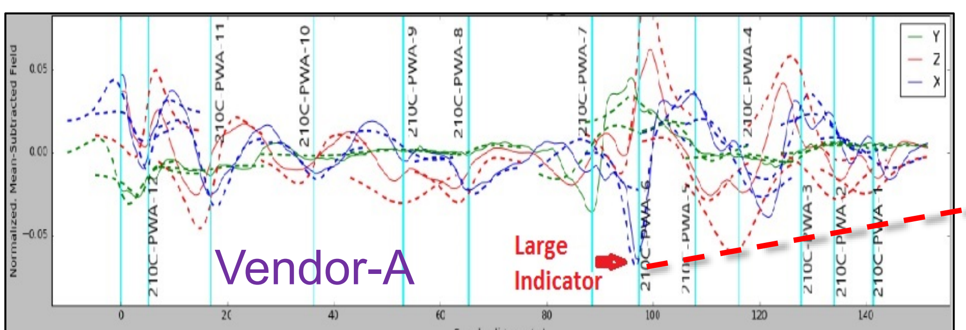
2 major error sources:

- Stress estimation error
- GPS positioning error









Our Understanding So Far

- Lack of good fundamental understanding of LSM technology is the major issue facing the industry.
- At the current stage, LSM is a screening & monitoring tool to compliment high-resolution inspection tools by providing additional information for better assessment and prioritization of excavation.
- The promising viable applications that can be deployed in near term is “globally” elevated strain/stress screening & monitoring at geohazard sites, and pipeline 3D mapping.

Recommendations for Next Steps

1) In-depth fundamental study by streamlining industry-wide efforts among operators, technology providers, academic organizations, and government funding agencies

2) Identify and focus on 1 ~ 2 top priority applications that have real field deployment feasibility in the near or intermediate future

3) More open environment for information sharing globally

Thank You

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