A DECADE OF PIPELINE GEOTECHNICAL MONITORING USING DISTRIBUTED FIBER OPTIC MONITORING TECHNOLOGY

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Outline

- **Introduction**
- **The Technology**
  - o Measurement principle, interrogation unit, sensor
- **Geohazard detection with optical fibers**
  - o Physical quantity and Some Examples
- **Technology evolution and project timeline**
  - o Interrogation Unit, Sensors, Monitoring software, Projects Timeline
- **Conclusions**

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Introduction

	Type of climate	Geohazard
Mountain Range	Tropical	Landslide, erosion
	Temperate	Landslide, erosion
	Arctic/sub-arctic	Landslide, erosion, subsidence
	Arid/semi-arid	Landslide, erosion
Flat land	Tropical	Erosion, subsidence
	Temperate	Erosion, subsidence
	Arctic/sub-arctic	Erosion, subsidence
	Arid/semi-arid	Erosion (including dune migration), subsidence,
Subsea / Underwater	Shallow water	Erosion (including seabed migration and scouring)

- **Pipeline Geohazard Threats**
  - Erosion, Landslide, Subsidence
- **Optical fiber technology**
  - Pipelines are linear structures as optical fiber cables
  - Communication and sensing through the same fibers
  - Strain, temperature (and vibration) sensors
  - Distributed measurements
- **Fiber optic monitoring solutions for pipeline integrity monitoring being implemented as early as 2002**

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Distributed Sensing

- **Turning optical fibers into a fully distributed sensor**

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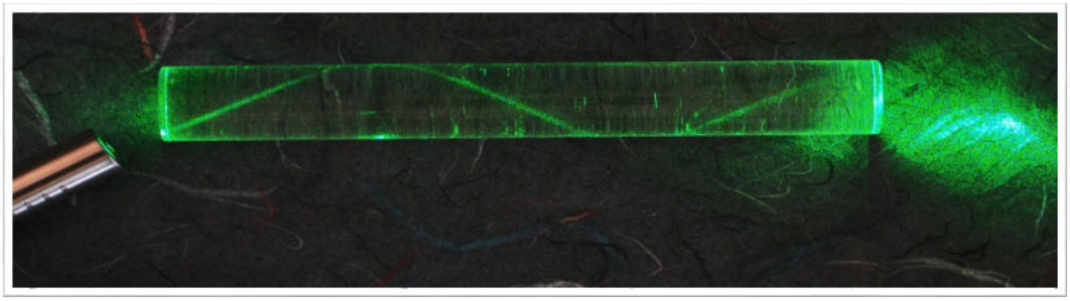
Light Scattering



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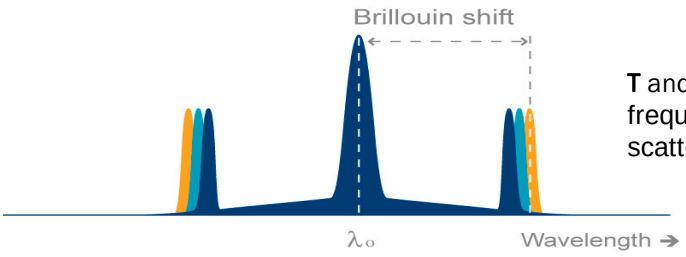
The physics behind detection and monitoring

- **Scattering analysis applied to sensing applications**
  - o Brillouin scattering lines are temperature and strain sensitive
  - o Peak frequency (Brillouin frequency) is proportional to strain and temperature



T and **ε** change in the fiber introduces frequency changes of Brillouin scattered light

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Sensing Technique

Time Domain

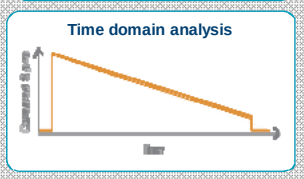
The activating signal is a propagating pulse and the position is given by the time of flight.

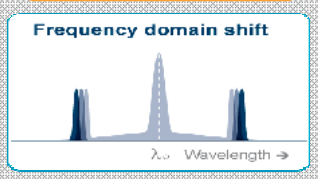
Spatial resolution is given by the pulse width.

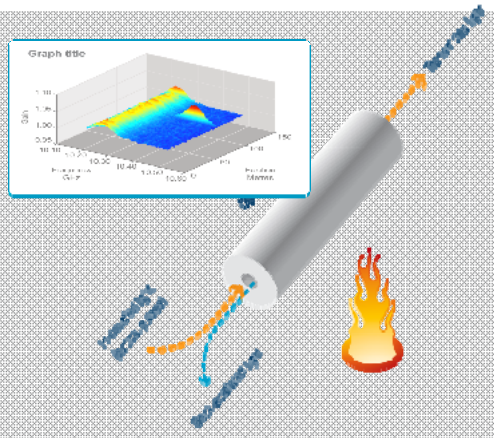
and

Frequency Domain

The frequency shift is computed by recording the Brillouin spectrum at different frequencies and extracting the maximum peak location.







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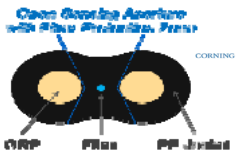
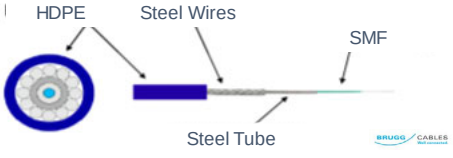
Optical Fiber Sensors - Strain

- **Strain Monitoring Cable**
  - Ground movement detection (landslide, subsidence)
  - Structure deformation
  - Compatible with direct burial
  - Mechanical strength and strain sensitivity
  - Specific cable design
  - Standard IEC 794-1





Iten et Al, SHMII 2009
Ravet et Al, ASME IPG 2013
IEC 60793 & 60794

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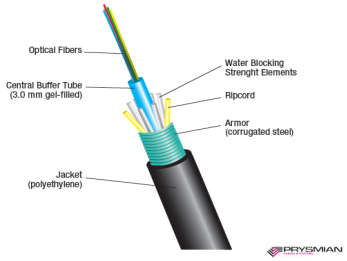
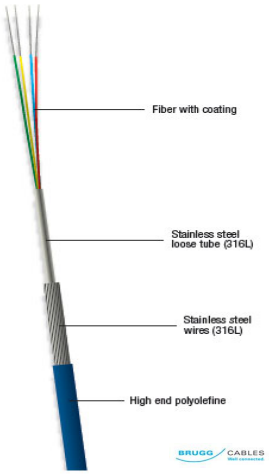
Optical Fiber Sensors - Temperature

- **Temperature Monitoring Cable**
  - Leak, seepage and erosion detection
  - Compatible with direct burial
  - Mechanical strength
  - Fiber mechanical isolation
  - Telecom cable
  - IEC 794-1





Ravet et Al, ASME IPG 2013
IEC 60793 & 60794

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Geohazard Detection and Monitoring

Geohazard	Soil Strain Measurement	Soil Temperature Measurement
Erosion		X
Subsidence	X	
Landslide	X	

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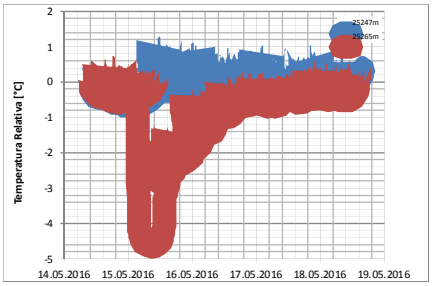
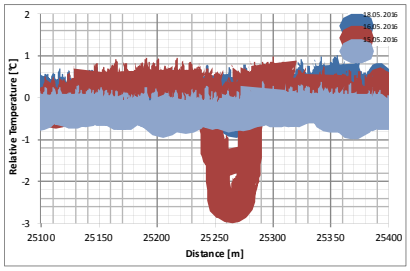
Erosion Detection and Monitoring

Ramones Transport System, Mexico





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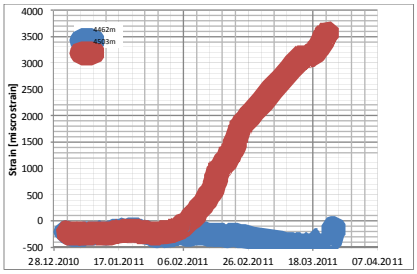
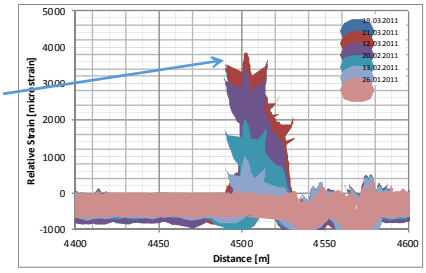
Landslides Detection and Monitoring

PLNG Transport System, Peru



Peak corresponds to a calculated displacement of about 25 cm



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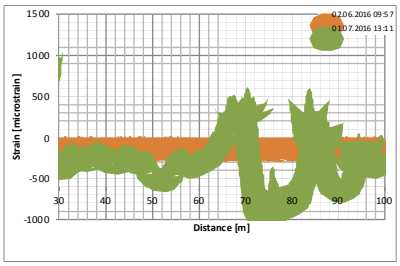
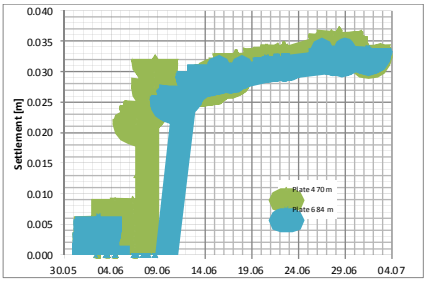
Subsidence Detection and Monitoring





Texcoco Lake, Mexico

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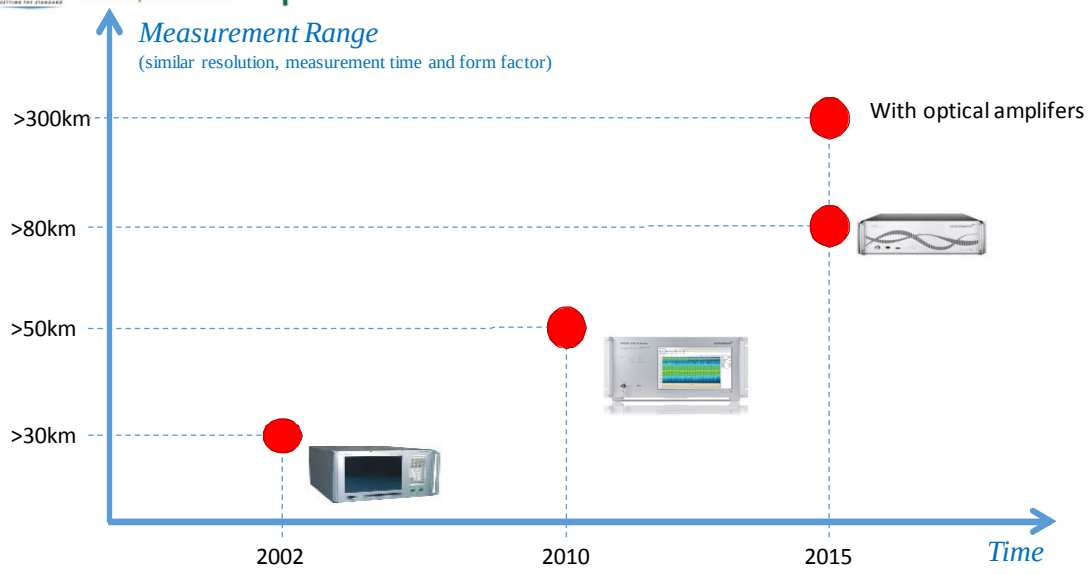
Performance Evolution



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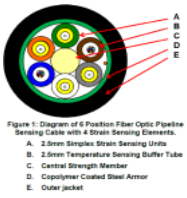
Sensing Cable Evolution

Better protection and multifunctional (telecom, strain, temperature, vibration)

AIMCOM



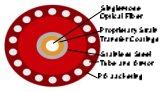
SMC DIAL

Better strain sensitivity and strength, lighter
Ground movement, Structural deformation

2015

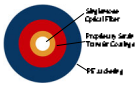
SMC-3

Improved strain sensitivity and strength



2010

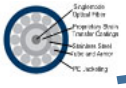
SMC-4



Enhanced strain sensitivity for Structural deformation

SMC-0

Strain sensing for ground movement



2008

Temperature and telecom

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Geotechnical monitoring integration to a comprehensive monitoring solution and non exhaustive installed Project History

Start of operation	Projects	Terrain and Climate	Country of Installation	Monitored Length	Geohazards	Other applications	Type of installation
2002	Berlin Brineline	Flat land and temperate	Germany	55 km	Erosion	Leak	During construction
2005	SNAM/Rete Gas (ENI) pipeline	Mountain range and temperate	Italy	500 m	Landslide, rock fall, erosion, pipeline deformation	Leak	Retrofit
2007	Pioneer Oooguruck Flowline	Subsea and subarctic	Alaska	7 km	Erosion	Leak	During construction
2009	Mineria Los Pelambres pipeline	Mountain range and arid	Chile	30km	Erosion	Leak	Retrofit
2010	Peru LNG pipeline	Mountain range and tropical	Peru	60 km	Landslide, rock fall, erosion	Leak	During construction
2010	ENI Nikaitchuq Flowline	Subsea and subarctic	Alaska	5 km	Erosion	Leak	During construction
2011	Transportadora de Gas del Peru pipeline	Mountain range and tropical	Peru	50 km	Landslide, rock fall, erosion	Leak	Retrofit
2011	Esperanza mine pipeline	Mountain range and arid	Chile	150 km	Erosion	Leak	During construction
2012	Sierra Gorda pipeline	Mountain range and arid	Chile	150 km	Erosion	Leak	During construction
2013	Sakhalin to Vladivostok pipeline	Mountain range, flat land and subarctic	Russia	1800 km	Landslide, rock fall, erosion, deformation		During construction
2013-2014	GASCO Pipelines	Flat land and arid	Abu Dhabi	250 km	Erosion	Leak	During Construction
2015	Ramones I pipeline	Flat-land and tropical	Mexico	114 km	Erosion	Leak and Third party intrusion	During construction
2016	Ramones II Norte pipeline	Mountain range and tropical	Mexico	460 km	Landslide, rock fall, erosion	Leak and Third party intrusion	During construction

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Conclusions

- **Technology evolved**
  - Better sensing performance and longer range
  - Sensors are more robust and sensitive or have multifunctional capabilities
  - Monitoring and data processing is more accurate and user friendly
  - Standardization activity on interrogation units (IEC 61757-3-1)
  - Performance evolution opens the application of the technology to long tiebacks and the access to remote area
- **Geohazard risk can be mitigated**
  - Early detection which allows preventive action to be taken
  - Installation during pipeline construction allows detection of landslides in unexpected locations
- **Challenges**
  - Appropriate cable selection
  - Cable installation
  - Robustness to survive the environment
  - Accurate position registration

Muchas gracias.

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