Monitoring Ground Support Workshop

Conceptual Framework for Unlocking of Value from Extensometer Data

A.J. Hyett

YieldPoint Inc

June 2022

YieldPoint *Sensing the future*

Unlocking Value

Monitoring Ground Support Workshop

Monitoring Performance of Ground Support Workshop

Associated event at:

Ninth International Symposium on Ground Support in Mining and Underground Construction

October 22nd 2019

ASSOCIATED EVENT

TUESDAY | 22 OCTOBER	WEDNESDAY | 23 OCTOBER	THURSDAY | 24 OCTOBER	FRIDAY | 25 OCTOBER
Monitoring Performance of Ground Support Workshop	Ninth International Symposium on Ground Support in Mining and Underground Construction		
		Symposium Dinner	

Monitoring Performance of Ground Support Workshop

22 October 2019 | Ballroom, The Radisson Hotel | Sudbury, Canada

Workshop Overview

Ground support is one the main control measure to mitigate the risk of rockfalls and rockbursts in underground mines. Designers must ensure the capacity of the support system will exceed the demand due to the dead weight of rockmass damage and loosening, as well as the dynamic stress waves induced by seismic events.

There are many challenges in assessing the capacity of ground support systems. For example, as soon as the ground support is installed a degradation process begins. The capacity of the support system is gradually consumed due to, amongst other factors, ground deformation, corrosion, and repeated dynamic loading from seismic events. It is the responsibility of mine operators to rehabilitate ground support when the capacity no longer meets the demand specified in the design criteria. ***Hence, it is extremely important to monitor the performance of ground support systems over time.***

In recent years, new and promising technologies, including lidars, drones, data acquisition and underground Wifi, can be packaged to enable a better understanding of the ground support capacity degradation. Some of them have shown promising results, but they still have limitations.

Workshop Objective and Format

This workshop will explore the current status of different emerging technologies and how they can be applied to monitor the performance of ground support. The programme is divided into two themes: the morning session will examine the technologies focussing on convergence measurements from repeated laser surveys. The afternoon session is dedicated to instrumentation of reinforcement and surface support.

For each theme, the format will involve a series of presentations from technology suppliers/developers, followed by an open discussion lead by a panel of experts carefully selected based on their extensive experience and knowledge on applying these technologies.

Workshop Facilitators

Professor John Hadjigeorgiou
Pierre Lassonde Chair in Mining Engineering
University of Toronto, Canada

Professor Yves Potvin
Professor of Mining Geomechanics
Australian Centre for Geomechanics,
Australia

Workshop Preliminary Programme*

Tuesday 22 October 2019	
07:30	Registration
08:15	**Welcome and introduction** *Professor Yves Potvin, Australian Centre for Geomechanics, Australia*
THEME 1: Convergence measurements from repeated laser surveys *Facilitator: Professor Yves Potvin*	
08:30	**Title TBA** *GroundProbe Pty Ltd*
09:00	**Use of aerial and ground drones to assess ground movements in underground mines** *Dr Syed Naeem, Clickmox Solutions Inc.*
09:30	**Mobile LiDAR solution for underground convergence monitoring and assessment: a case study** *Curtis Watson, Pecktech*
10:00	[illegible] *Matt MacKinnon, Unmanned Aerial Services Inc.*
10:30	Morning break
11:00	**Panel discussion** *Peter Andrews, VP and Group Head of Geotechnical, Gold Fields Australia Pty Ltd, Australia; Dave Counter, Senior Ground Control Engineer, Glencore Canada Coproration; Dr Graham Swan, Independent Consultant*
12:00	Lunch
THEME 2: Instrumentation of reinforcement and surface support *Facilitator: Professor John Hadjigeorgiou, University of Toronto*	
13:00	**A contribution through instrumentation to a better understanding of rockmass behaviour and ground support performance in a high stress mine enviroment** *Allan Punkkinen, Normet Canada Ltd.*
13:30	**A conceptual framework for unlocking of value from instrumentation data** *Dr Andrew Hyett, YieldPoint Inc.*
14:00	**The application of instrumentation** *Peter Lausch, Mine Design Technologies Inc.*
14:30	**An innovative rockbolt sensing technology to transform rockbolts into a network of ground condition sensors** *Silvio Kruger, National Research Council of Canada*
15:00	Afternoon break
15:30	**Panel discussion** *Professor Bruce Hebblewhite, Professor Mining Engineering, UNSW Sydney, Australia; Brad Simser, Principal Ground Control Engineer, Glencore; Dr Mike Yao, Manager of Rock Engineering, Vale Canada Ltd*
16:30	**Workshop wrap-up** *Professor Yves Potvin*
16:45	Workshop close

*Programme is subject to change.

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Preamble

Motivation

“The price of light is less than the cost of darkness”

Science :

Deeper understanding of rock mass behavior to promote more efficient underground excavation design.

Business:

Unlock more value from the data that is collected, with a focus on proactive geotechnical management which requires forward-looking projections.

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Page 1 / 1

The Story So Far

Pre 1995: Civil engineering instruments. Vibrating wire. IRAD stress meters.
Large extensometer heads vulnerable to mining activity.

Hoek, Kaiser and Bawden (1995) Support of Underground Excavation in Hard Rock, did present a single *in situ* monitoring result.

1995-2005: Mining Specific Instrumentation.
Develop instrumentation specifically for mining. GMMs.
SMART Cable/MPBXs.
Improve reliability. Early digital instruments.

2005-2015: Data-loggers and telemetry. Develop and improve instrumented rockbolts. Telemetry: NewTrax etc.

2015-pres: The IoT era:
Low cost telemetry.
Zigbee and Bluetooth 5.0.
Wireless instruments.
Widespread WiFi mines. LTE coming.

Excavation scale monitoring as opposed to seismic system providing mine-wide monitoring.

E HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **89**

OTECHNICAL INSTRUMENTATION FOR MONITORING FIELD PERFORMANCE

JOHN DUNNICLIFF
Geotechnical Instrumentation Consultant
Lexington, Massachusetts

Topic Panel
MICHAEL BOZOZUK, *National Research Council of Canada*
ROGER D. GOUGHNOUR, *Federal Highway Administration*
JOHN W. GUINNEE, *Transportation Research Board*
JOSEPH B. HANNON, *California Department of Transportation*
VERNE C. MCGUFFEY, *New York State Department of Transportation*
ERNEST T. SELIG, *University of Massachusetts*

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. APRIL 1982

1990s Motivation:

To generate data that could be used to calibrate numerical models that can then be used for design of support (Phases, FLAC), and hence to better understand the mechanics of rock mass/ ground support interaction.

BUT: This never happened. Why not?

The Geotechnical Model Calibration Conundrum

1. *Initial Condition uncertainty.*

The vast majority of instruments are installed around a pre-existing excavation which has already undergone deformation before installation

This is a problem because chaotic/complex geotechnical systems are distinguished by sensitivity to the initial conditions

2. *The stress/displacement dichotomy.*

Displacements are easy to **measure but very difficult to model accurately**

In contrast:

Stress changes are relatively easy to **model but devilishly difficult to measure**.

Stress/ stress Change:	EASY to model,	DIFFICULT to measure
Displacement:	DIFFICULT to model,	EASY to measure

Computer simulations of stresses are reasonable, displacements are rarely close.

Monitoring Ground Support Workshop

The Geotechnical Model Calibration Conundrum

3. Time: ***An Inconvenient truth for Hard Rock geomechanics***

Instrumentation datasets are very rich in the time-domainwith readings every 1hr or every 10mins

whereas

standard geotechnical models do not have time-dependent constitutive behavior.

4. **Scale: *How to upscale 2 orders of magnitude?***

Extensometers **measure** on meter scale.
Engineering models/simulations are based on laboratory test results at cm scale.

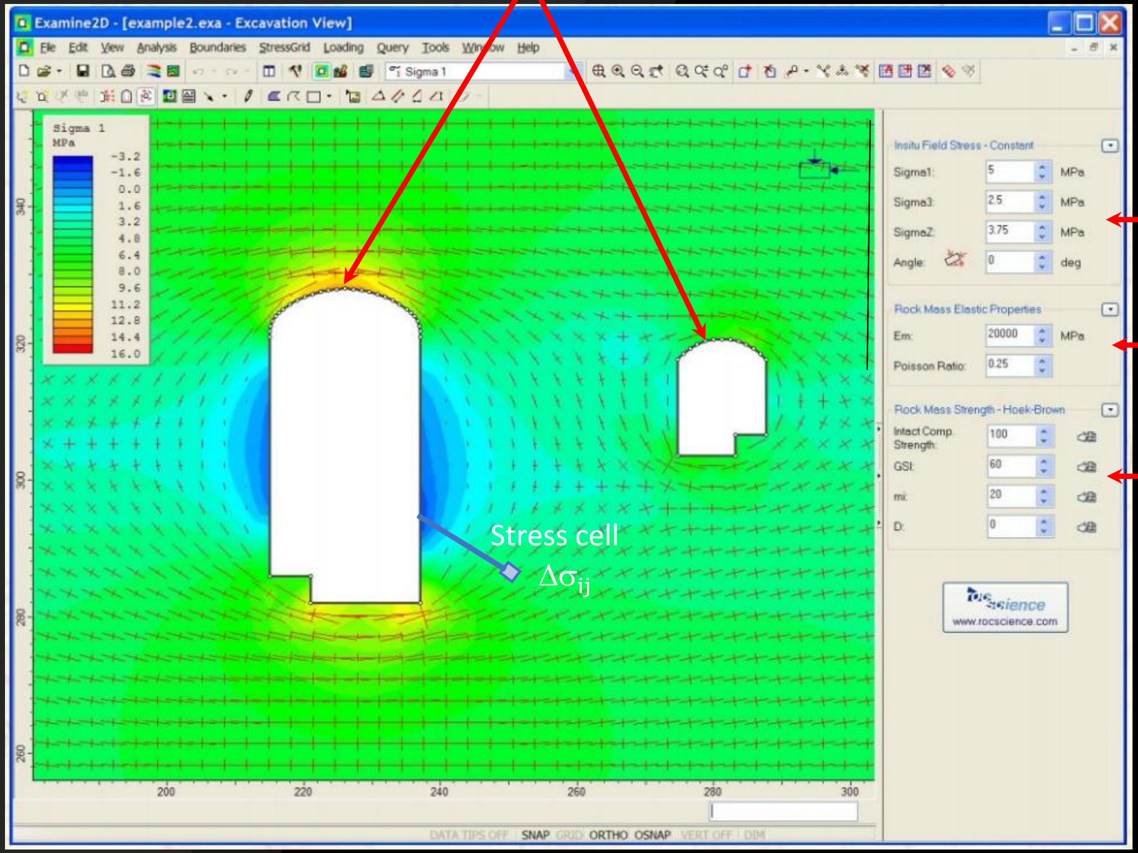
What about stress cell calibration using elastic models?

Boundary conditions for excavations are posed in stress.

Hence calibration of stress change with stress cells ($\Delta\sigma_{ij}$) is **only a "geometric" calibration of far field stresses, not a true mechanical calibration.**

Stress redistribution is only a function of excavation geometry and far field stress.

Traction free boundaries



Far field stress

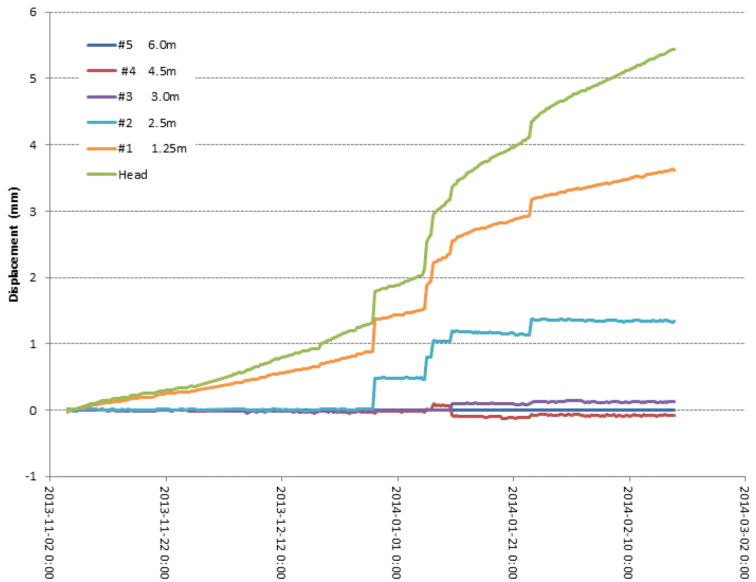
Only affect displacement

No effect on stress or Displacement solution

To simulate ground support realistically displacements are required

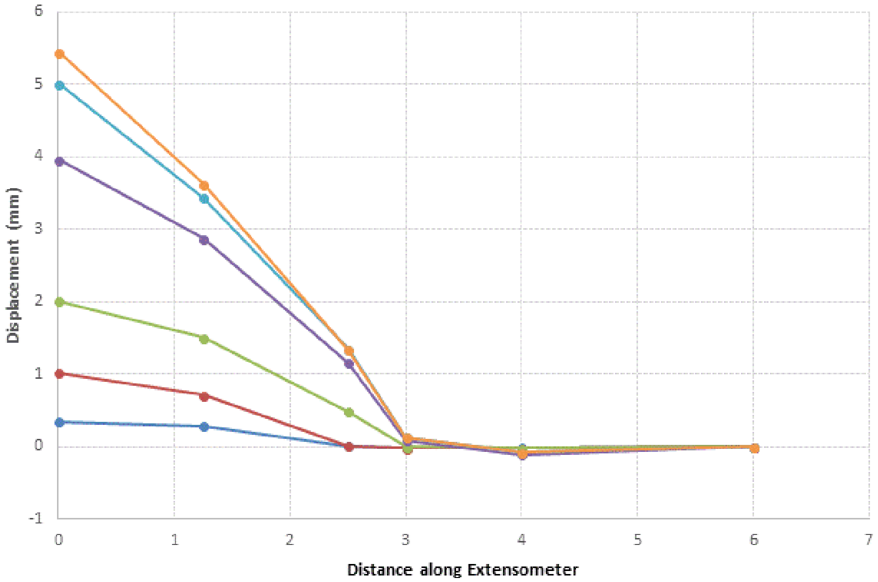
Patterns in the MPBX data

Temporal Graph



Rich time-series plots

Spatial Graph



Limited spatial content

1. **Temporal Domain:** *Displacement Velocity + Acceleration*

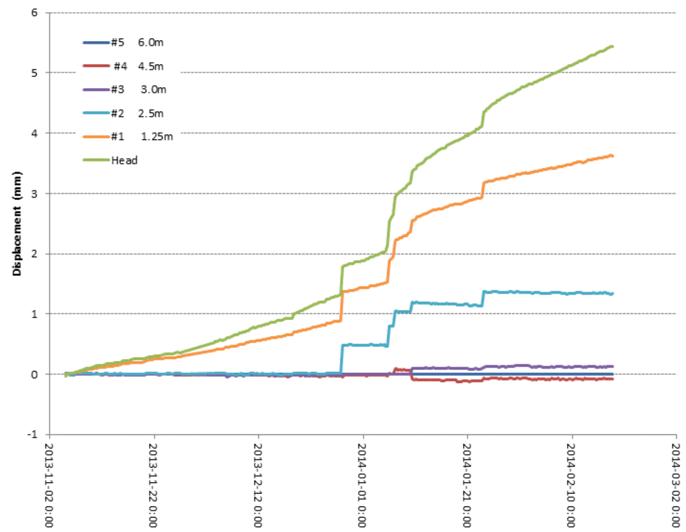
   1.1. Events:
   - a. Blasting Events
   - b. Seismic Events

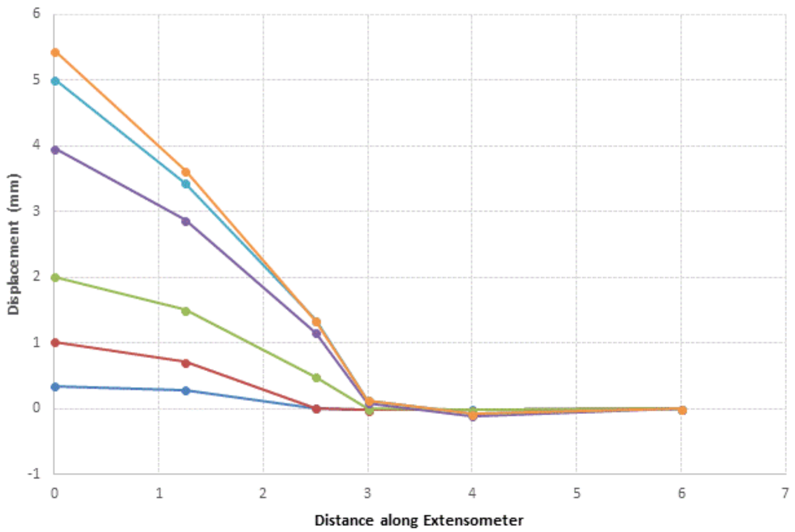
   1.2. Time dependency:
   - **a. Brittle Creep**
   - **b. Stress Factor(σ/σ_F)**

2. **Spatial Domain:** *Strain, Strain rate*

   2.1 Strain.
   2.2. Rock Support Condition.
   2.3. Localization

3. Pulling it all together into an **Excavation Management Solution**





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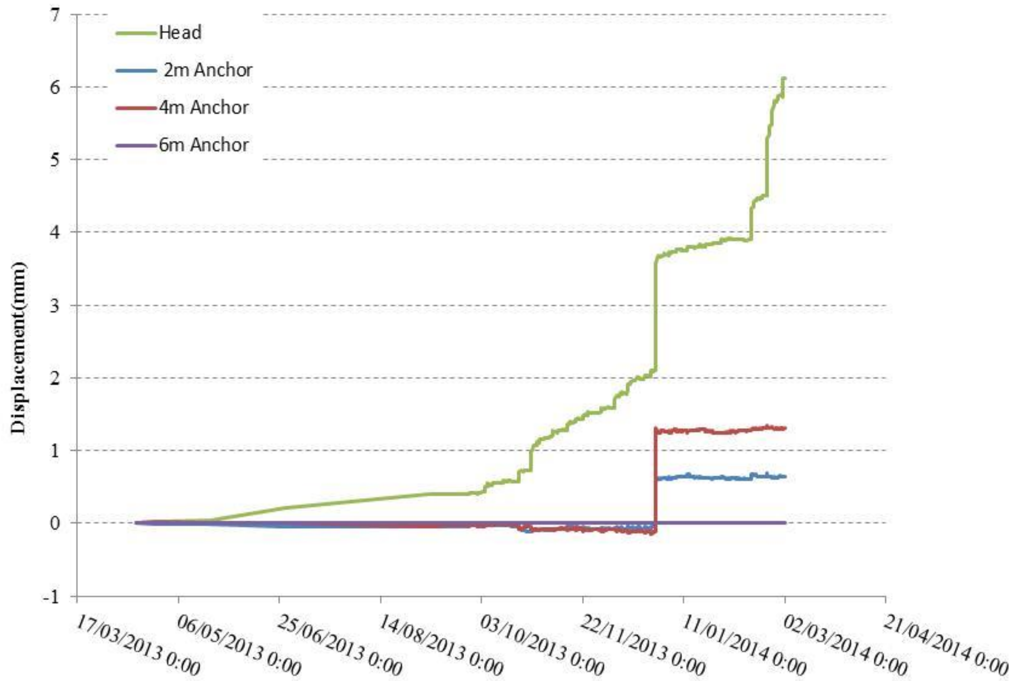
Outline of Presentation

Higher order Variables: Displacement Rate/Velocity (mm/day)

7800 Level Creighton Mine, Sudbury



Circa 2010: Low noise, higher res instruments + low cost data loggers

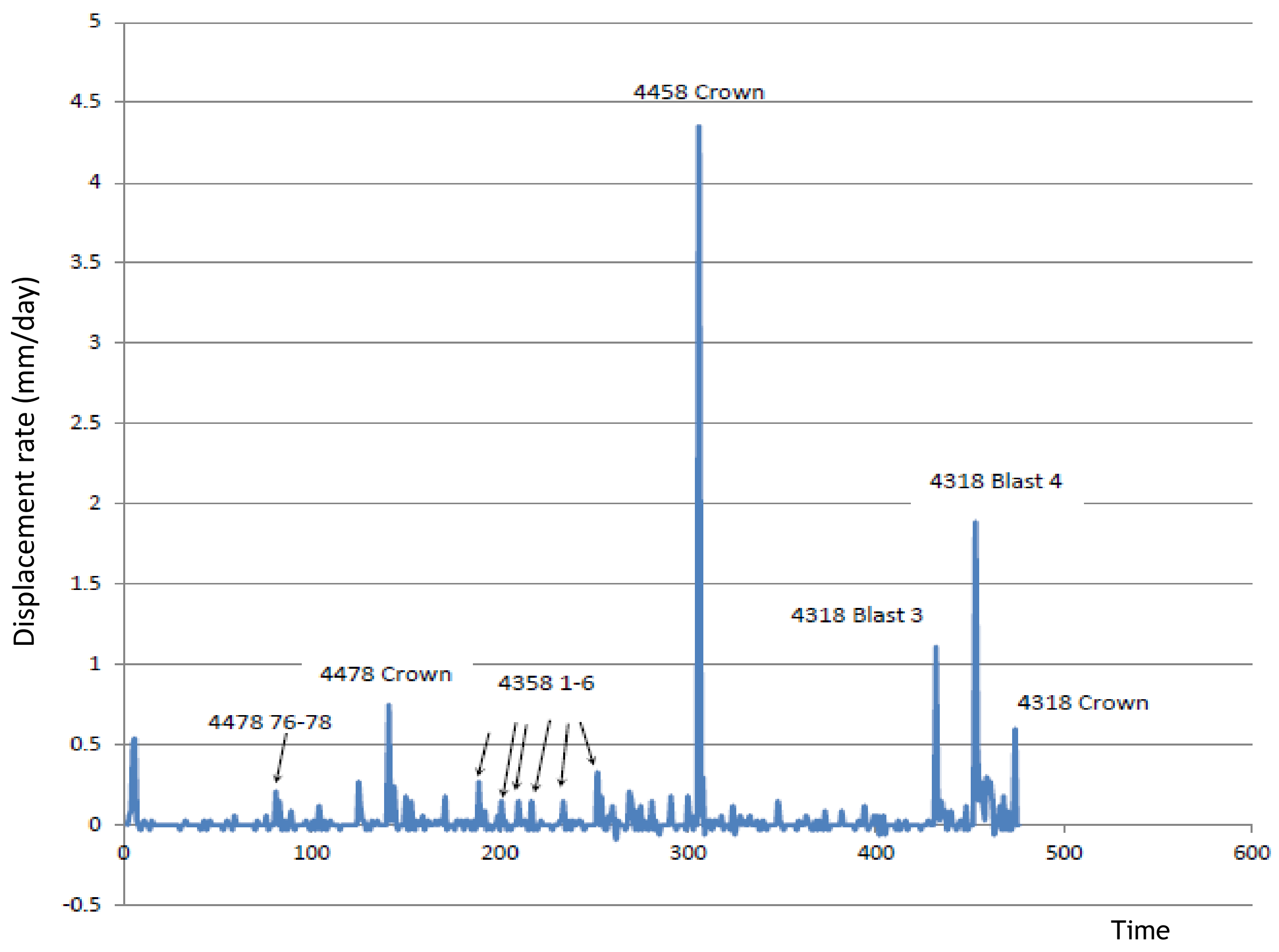
8hr interval

Delta

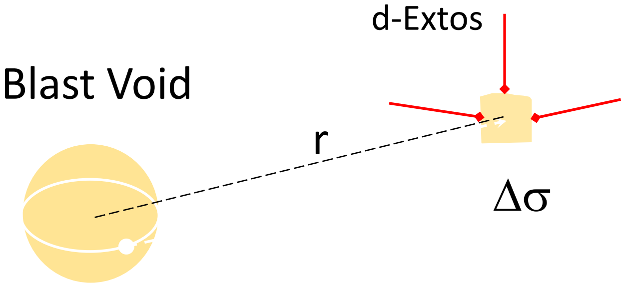
190	130441002 2013/11/06 08:00:22	06/11/2013	8:00:22	33.3	30.33	31.9	34.18			0
191	130441002 2013/11/06 16:00:21	06/11/2013	16:00:21	33.3	30.32	31.89	34.18			0
192	130441002 2013/11/07 00:00:21	07/11/2013	0:00:21	33.3	30.33	31.88	34.18		2nd	0.03
193	130441002 2013/11/07 08:00:21	07/11/2013	8:00:21	33.3	30.35	31.91	34.21			-0.01
194	130441002 2013/11/07 16:00:21	07/11/2013	16:00:21	33.3	30.35	31.9	34.2			0
195	130441002 2013/11/08 00:00:21	08/11/2013	0:00:21	33.3	30.35	31.9	34.2			0
196	130441002 2013/11/08 08:00:22	08/11/2013	8:00:22	33.3	30.36	31.9	34.2			-0.01
197	130441002 2013/11/08 16:00:21	08/11/2013	16:00:21	33.3	30.35	31.89	34.19			0
198	130441002 2013/11/09 00:00:21	09/11/2013	0:00:21	33.3	30.36	31.88	34.19			0
199	130441002 2013/11/09 08:00:21	09/11/2013	8:00:21	33.3	30.36	31.88	34.19			0.02
200	130441002 2013/11/09 16:00:21	09/11/2013	16:00:21	33.3	30.38	31.88	34.21			-0.01
201	130441002 2013/11/10 00:00:21	10/11/2013	0:00:21	33.3	30.38	31.88	34.2		3rd	0.05
202	130441002 2013/11/10 08:00:22	10/11/2013	8:00:22	33.3	30.41	31.96	34.25			0
203	130441002 2013/11/10 16:00:22	10/11/2013	16:00:22	33.2	30.4	31.96	34.25			0.01
204	130441002 2013/11/11 00:00:22	11/11/2013	0:00:22	33.2	30.42	31.95	34.26			-0.01
205	130441002 2013/11/11 08:00:22	11/11/2013	8:00:22	33.2	30.42	31.95	34.25			0
206	130441002 2013/11/11 16:00:21	11/11/2013	16:00:21	33.2	30.42	31.94	34.25			-0.01
207	130441002 2013/11/12 00:00:21	12/11/2013	0:00:21	33.1	30.41	31.93	34.24			0
208	130441002 2013/11/12 08:00:21	12/11/2013	8:00:21	33.1	30.41	31.93	34.24			0
209	130441002 2013/11/12 16:00:21	12/11/2013	16:00:21	33.1	30.41	31.92	34.24		4358	0
210	130441002 2013/11/13 00:00:21	13/11/2013	0:00:21	33	30.42	31.93	34.24		3:35 4th	0.05
211	130441002 2013/11/13 08:00:21	13/11/2013	8:00:21	33	30.45	32.02	34.29			0
212	130441002 2013/11/13 16:00:21	13/11/2013	16:00:21	33	30.45	32.01	34.29			0
213	130441002 2013/11/14 00:00:21	14/11/2013	0:00:21	33	30.46	32	34.29			0.01

Delta x 3 = mm/day

Displacement Rate or Velocity (mm/day)



a. $\Delta\sigma$ due to new void



$$\Delta\sigma_{ij} \;\alpha\; \frac{m}{\rho\, r^3}$$

Total Size of blast (tonnes) = *m*
Radius of void (m)= a
Void Volume (V) = m/ρ

Note: Elastic solution independent of E, ν

b. PPV at excavation wall

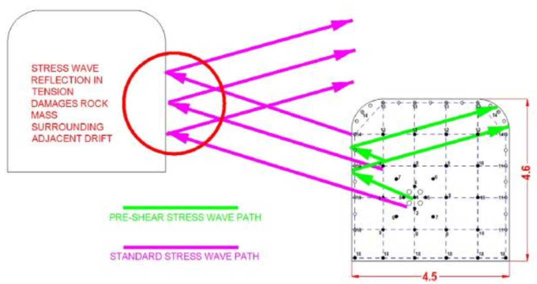


Fig. 7. Mechanism of stress wave induced damage at adjacent excavation. Length is in meter.

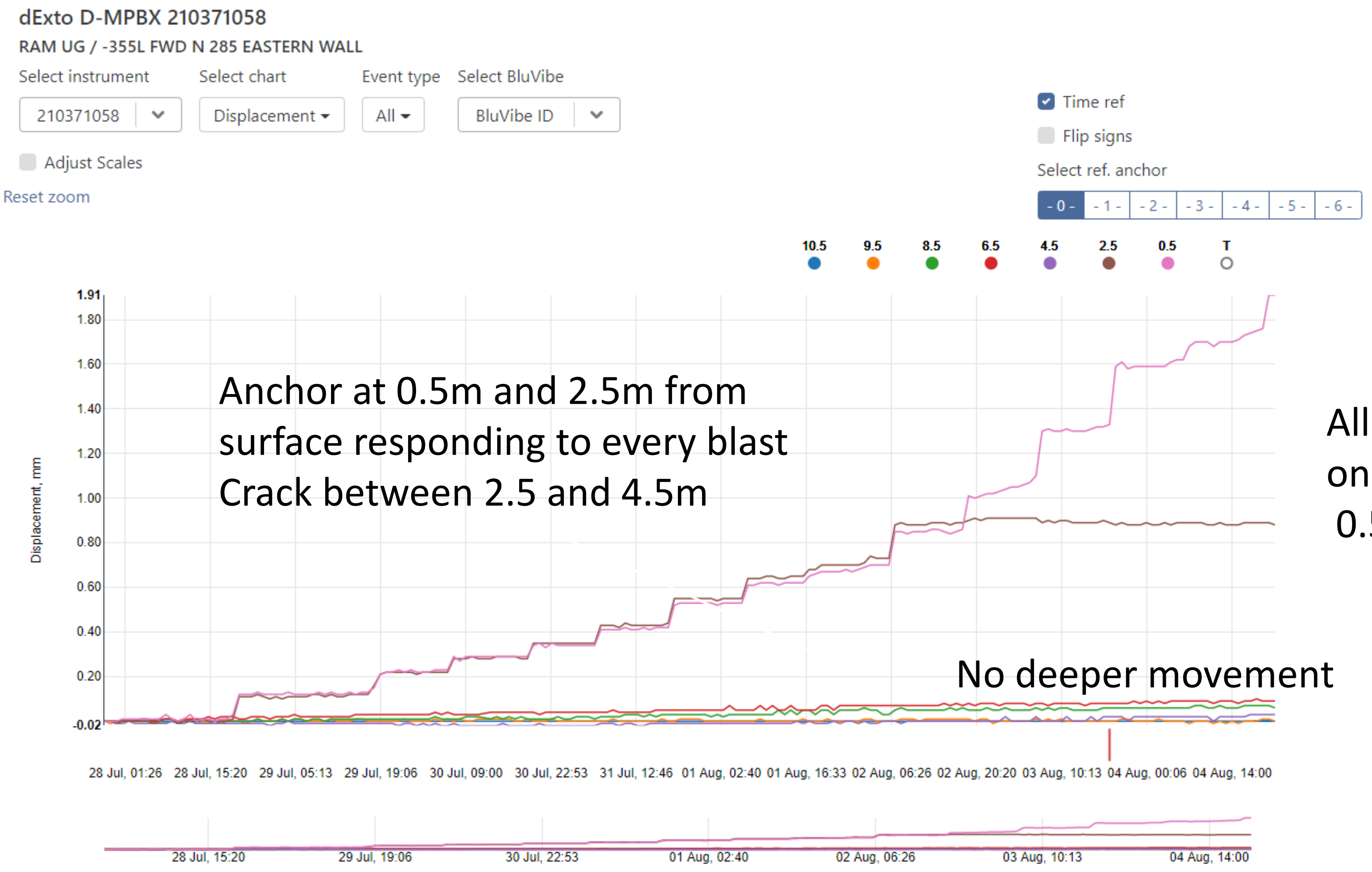
"It can be seen that during normal blasting, compressive stress waves are reflected in tension at the free surface of a nearby tunnel, causing damage to the tunnel at the rock/excavation boundary"

Yugo and Shin (2015), Wolverine Project

Velocity Amplification. Zhang *et al*. (2018)

1.1a Blast Events:

Displacement (mm) versus time



Range is only 2mm

Anchor at 0.5m and 2.5m from surface responding to every blast
Crack between 2.5 and 4.5m

All movement occurring on different crack(s) between 0.5 and 2.5m.

No deeper movement

Displacement Rate or Velocity (mm/day)

dExto D-MPBX 210371058

RAM UG / -355L FWD N 285 EASTERN WALL

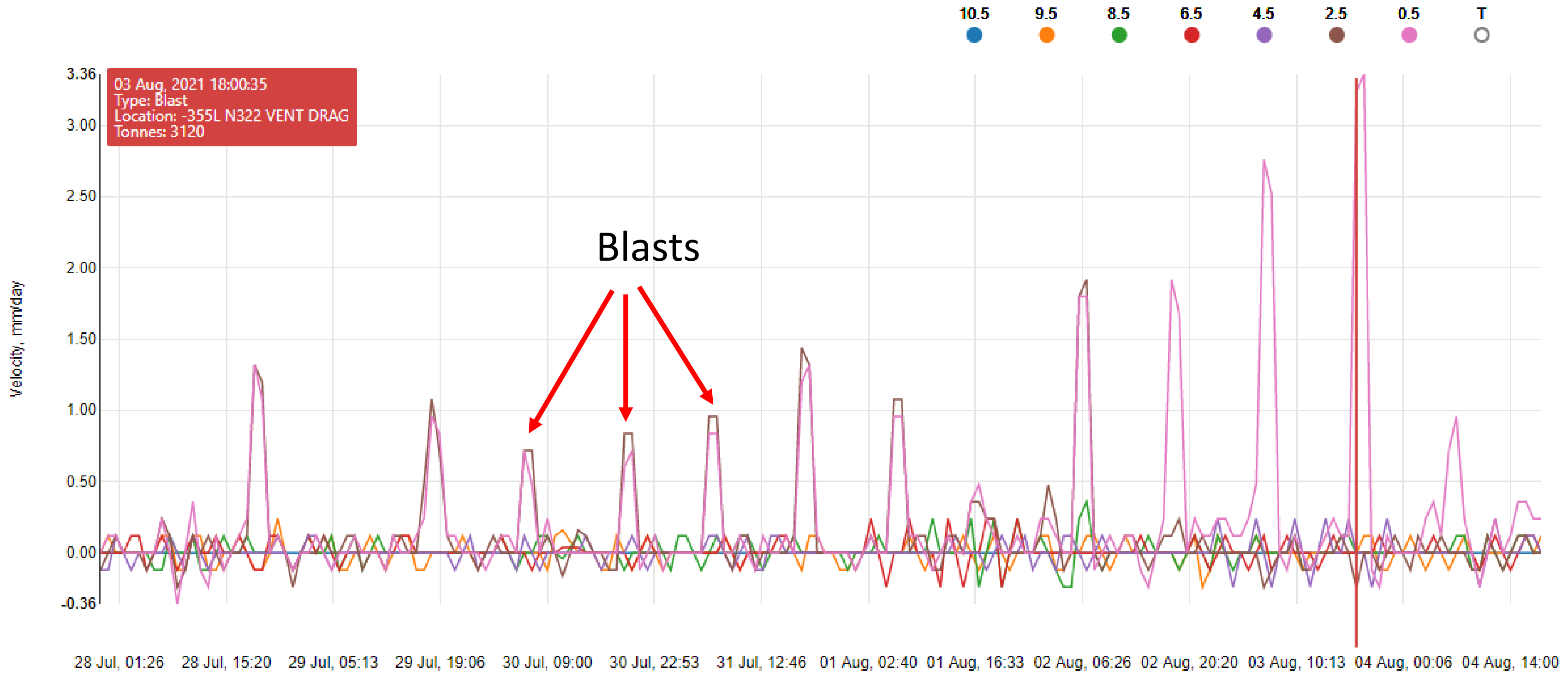
Select instrument: 210371058 | Select chart: Velocity | Group By: None | Event type: All | Select BluVibe: BluVibe ID

Flip signs

Select ref. anchor: - 0 - | - 1 - | - 2 - | - 3 - | - 4 - | - 5 - | - 6 -

Adjust Scales

Reset zoom



Conceptual Framework for Events->Damage

Scaled Distance Concept:

A small event that is nearby may have a similar impact (i.e. cause similar damage) as a large event that is more distant.

Scaled Distance is a commonly used technique for estimating the Vibration (PPV) and air overpressure from blasts. Also applies to attenuation of shock waves through rock. SD Determined from Blasting and micro-seismic datasets

Event (size, location) -> SD -> PPV -> Damage at excavation - Exto Data

$$PPV = K * SD^{-B}$$

Both of the variables, K and B, change significantly where K can vary from 10 to over 500 and B can vary from 0.8 to over 3.

Table 3 Vibration predicator equations*

Agency/institution and authors	Predictor equation
Langefors *et al.* equation (1958)[1]	$PPV = K\left[\left(\frac{Q}{D^{3/2}}\right)^{1/2}\right]^{B}$
USBM predictor equation (Duvall and Petcoff, 1959;[2] Siskind *et al.*, 1980[8])	$PPV = K\left[\frac{D}{(Q)^{1/2}}\right]^{-B}$
General empirical equation (Davies *et al.*, 1964;[3] Birch and Chaffer, 1983[4])	$PPV = KD^{-B}Q^{A}$
Ambraseys–Hendron equation (1968)[9]	$PPV = K\left(\frac{D}{Q^{1/3}}\right)^{-B}$
Indian Standard (1973)[10]	$PPV = K\left(\frac{Q}{D^{2/3}}\right)^{B}$
Ghosh–Daemen equation (1983)[11]	$PPV = K\left[\frac{D}{(Q)^{1/2}}\right]^{-B} \times e^{-\alpha D}$ $PPV = K\left(\frac{D}{Q^{1/3}}\right)^{-B} \times e^{-\alpha D}$
CMRI equation, India (Pal Roy, 1993)[5]	$PPV = n + K\left[\frac{D}{(Q)^{1/2}}\right]^{-1}$

*D: distance of the measuring transducer from blasting bench (m); K, B, A, n, α: site constants to be determined by regression analysis; PPV: peak particle velocity (mm s^{-1}); Q: maximum quantity of explosive charge per delay (kg per delay).

Cylindrical attenuation:
$SD = D/Q^{1/2}$

Spherical attenuation:
$SD = D/Q^{1/3}$

D: distance of the measuring transducer from blast (m);
Q: weight of explosive charge per delay (kg per delay).

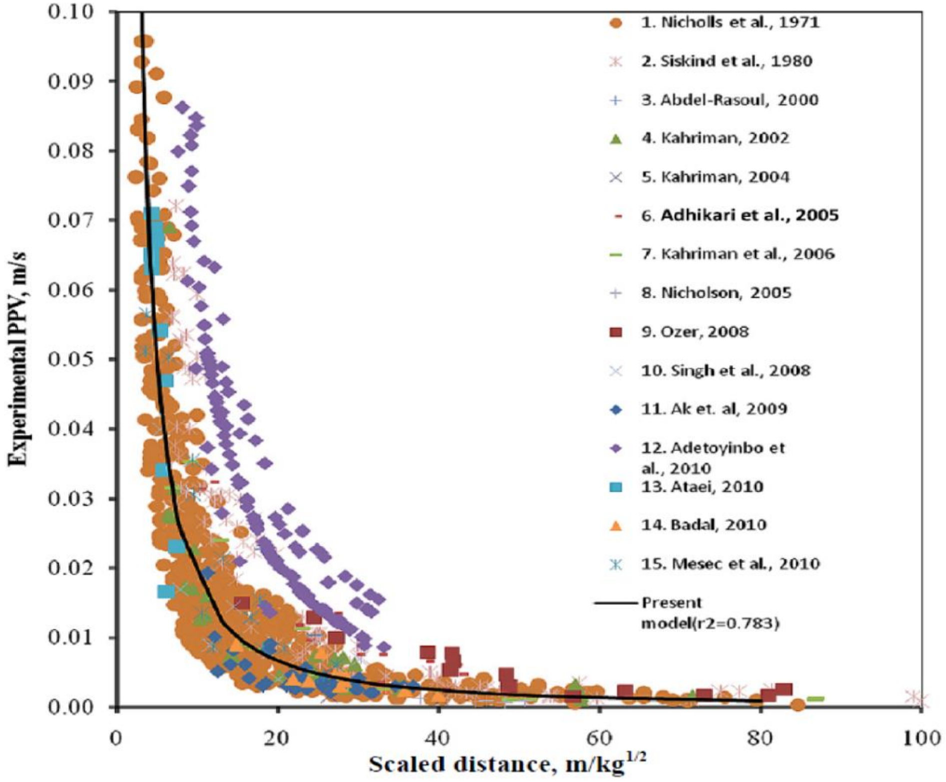


Fig. 1. Experimental PPV as a function of scaled distance.

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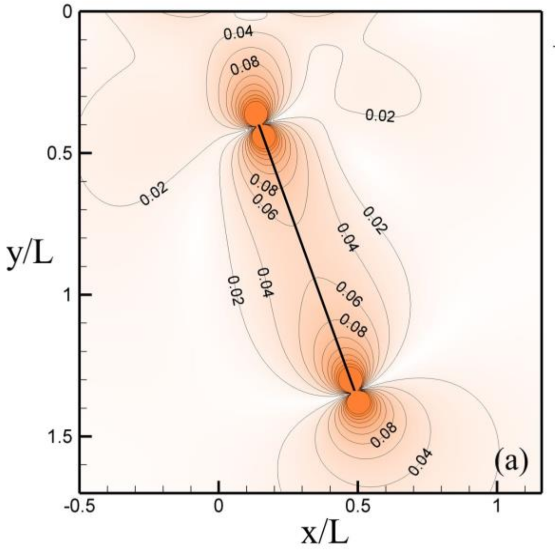
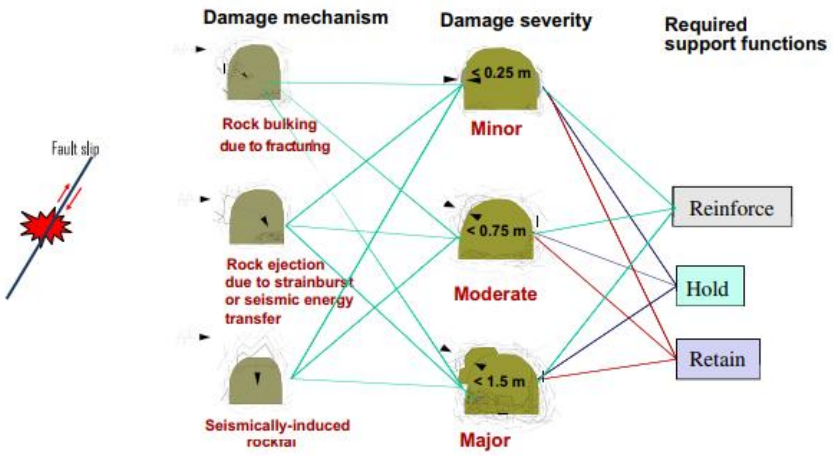
1.1a Blast Event:

a. $\Delta\sigma$ due Fault Slip



Stress redistribution/readjustment due to fault slip

b. PPV at excavation wall



Damage due to P and S waves passing through and reflecting off excavation boundary.

Amplification at excavation wall.

Monitoring Ground Support Workshop

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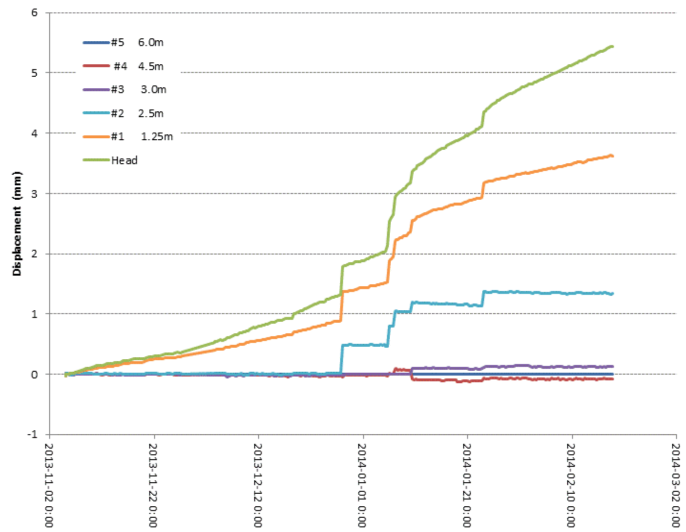
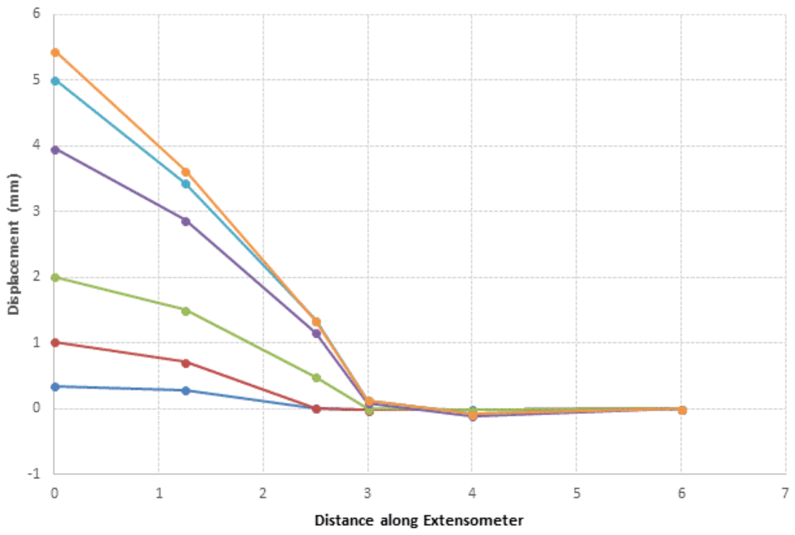
   1.2. Time dependency:
   a. Brittle Creep
   b. Stress Factor(s/s$_F$)

2. **Spatial Plot:** *Strain, Strain rate*

   2.1 Strain.
   2.2. Rock Support Condition.
   2.3. Localization

3. Pulling it all together into an
   Excavation Management Solution





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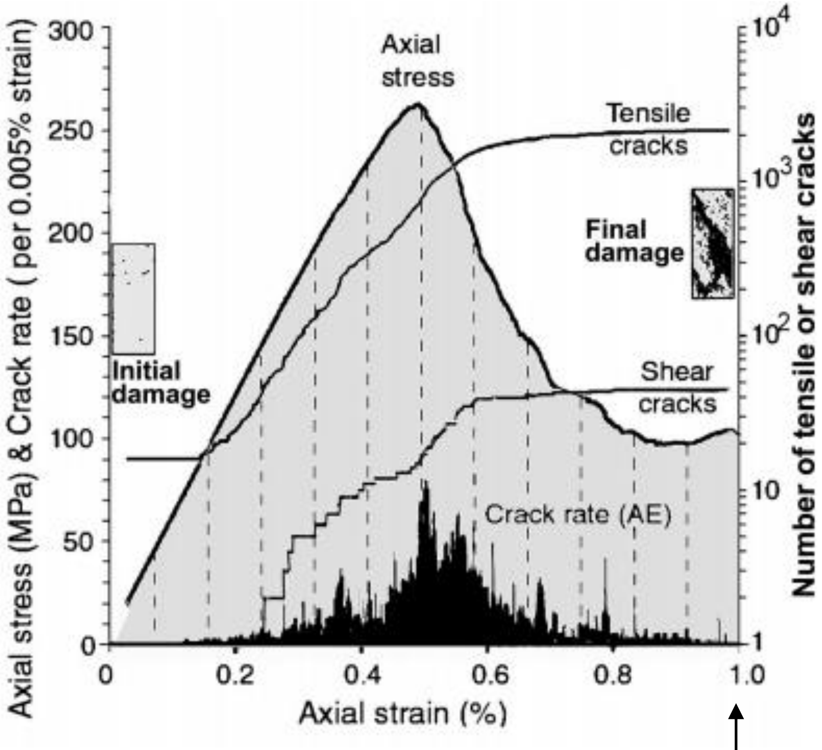
Outline of Presentation

Stress *v* Strain Failure behaviour - Constant Strain Rate test

Stress Factor (S.F.)=σ/σ_p



10mm Exto movement /over 1m anchor spacing

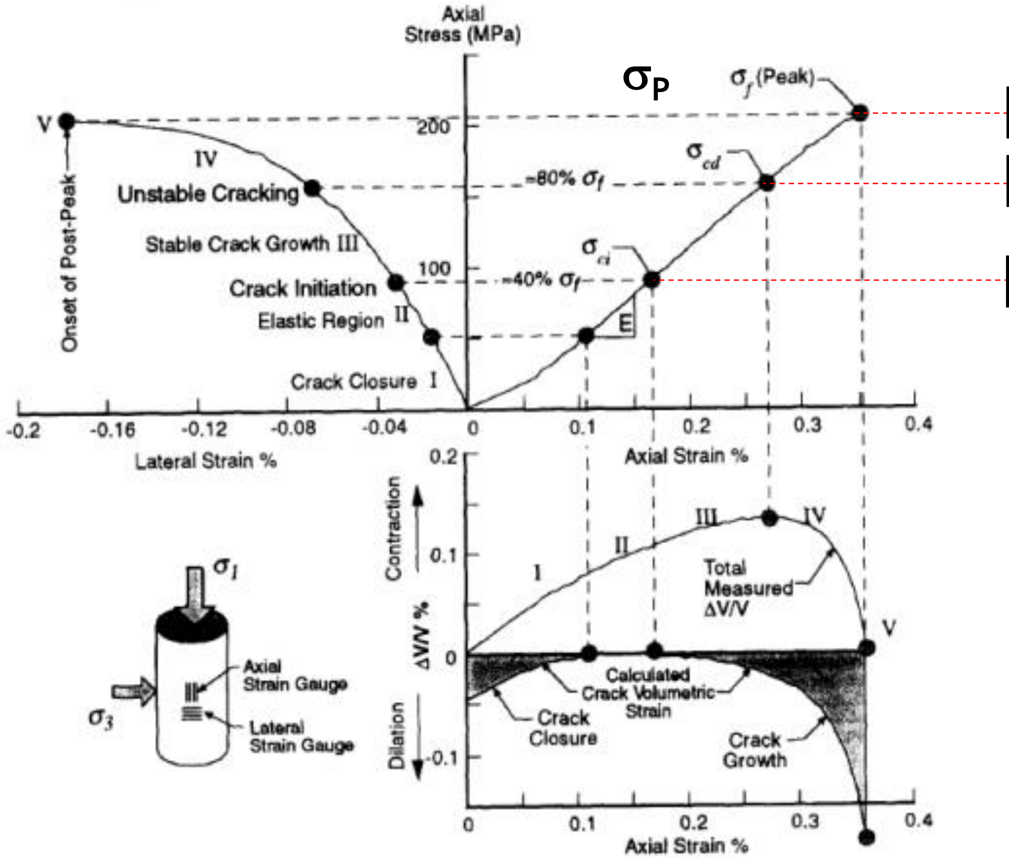
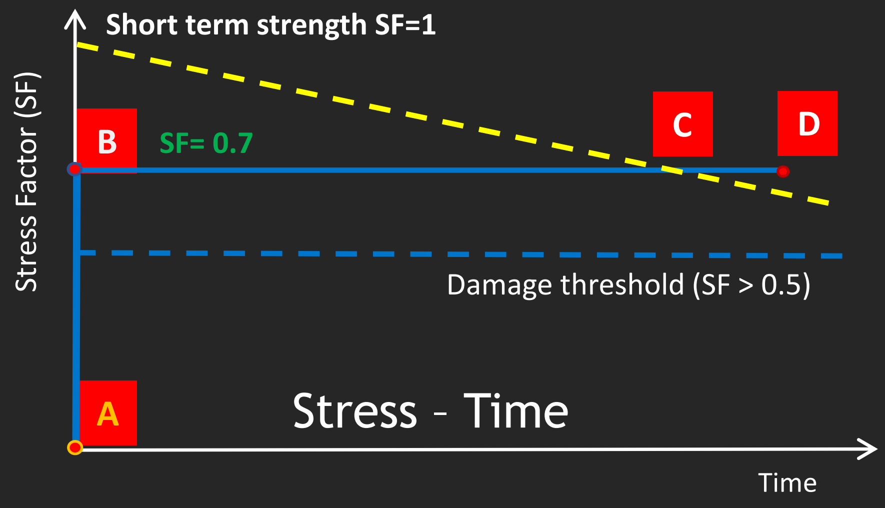
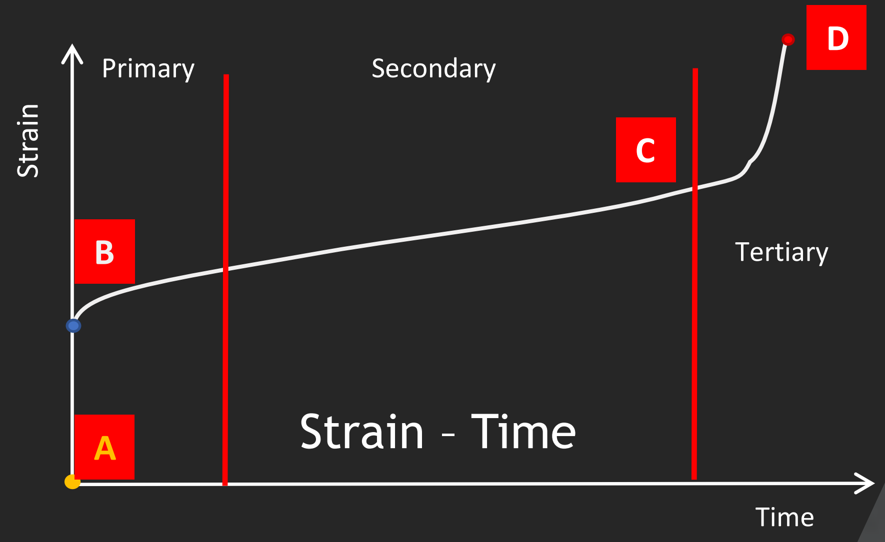
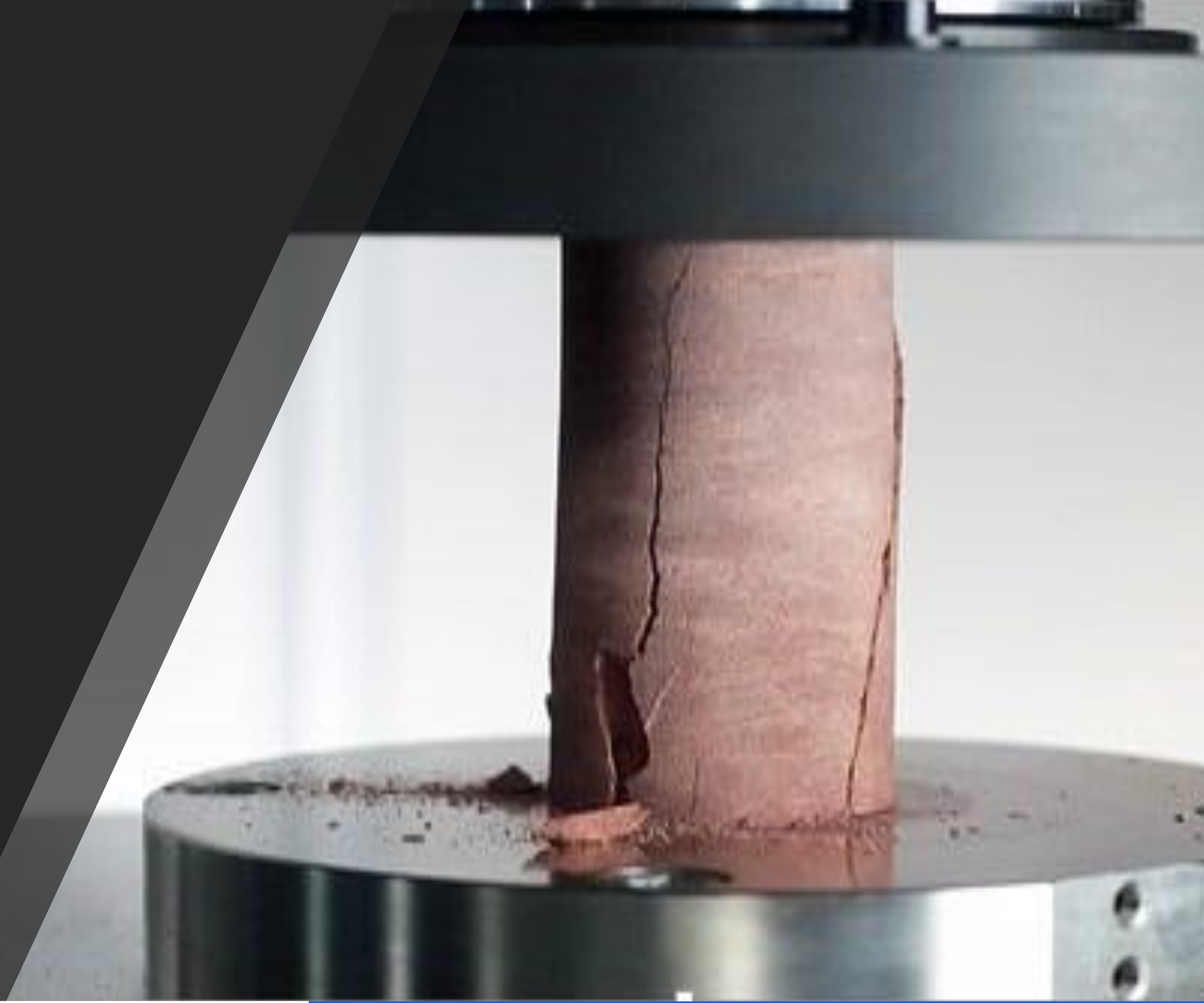


Figure 3. Stress strain plot of a uniaxial compression test on Lac du Bonnet granite showing the definition of crack initiation (σ_{ci}), crack damage (σ_{cd}) and peak strength (σ_f). [Source: Figure 1 in Martin & Chandler 1994]

Monitoring Ground Support Workshop



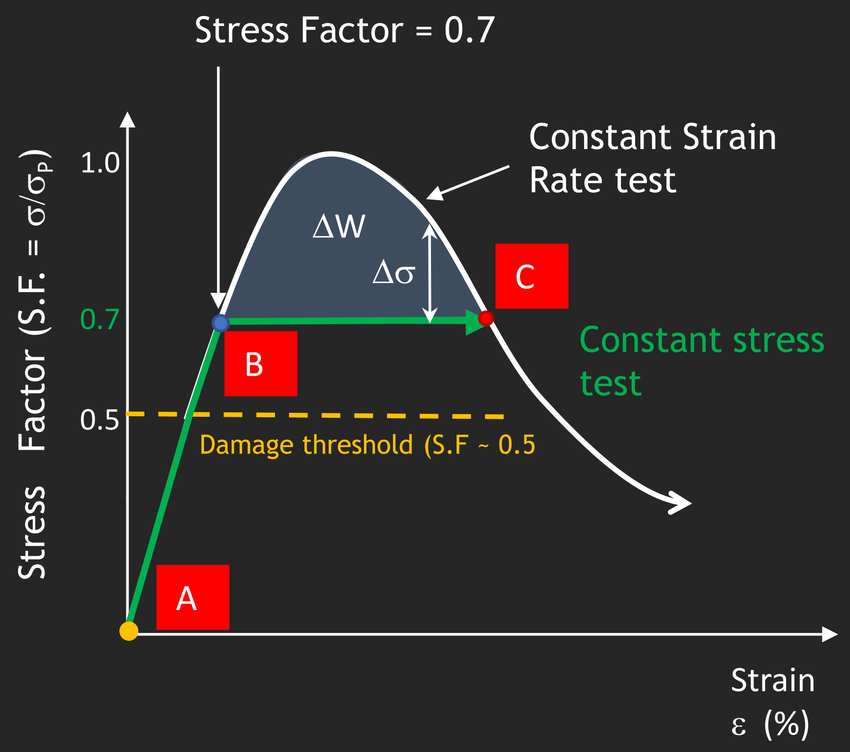




YieldPoint *Sensing the future*

1.2a Time dependency

The energy advantage for brittle creep versus constant strain rate failure



Area under the plot is the Energy (W) required to fail the specimen.

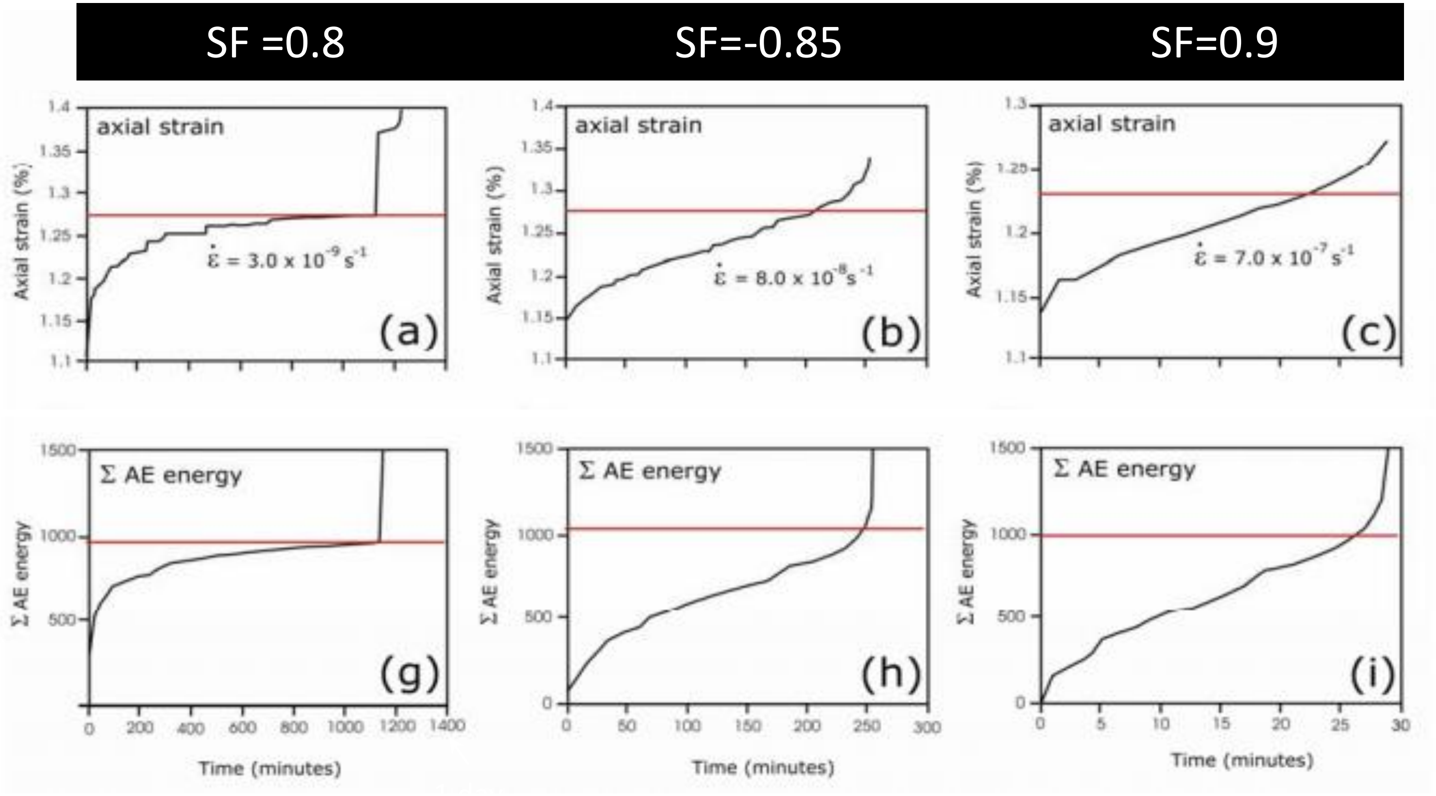
From energy perspective, less energy is required to fail the sample under constant stress versus constant strain rate

The creep test is more pertinent to the situation around an underground excavation

ΔW is the energy deficit.

$\Delta\sigma$ is the stress deficit.

Excavations will find the easiest path to release energy.



Creep tests for different Stress Factors (SF= σ/σ_P) (Heap 2009)

Around an excavation all of these conditions may co-exist

1.2a Time dependency:

Monitoring Ground Support Workshop

Malan's Work, CSIR

South African researchers (CSIR) using primitive closure stations in the 1990's were surprised to observed that close to the face the rock mass response was time-dependent.

Malan, D.F. Manuel Rocha Medal Recipient: Simulating the time-dependent behaviour of excavations in hard rock. Rock Mech. Rock Engng., vol. 35, no. 4, 2002.

Malan. F.D , Time-Dependent Behaviour of Deep Level Tabular Excavations in Hard Rock. Rock Mech. Rock Engng. (1999) 32 (2), 123-155

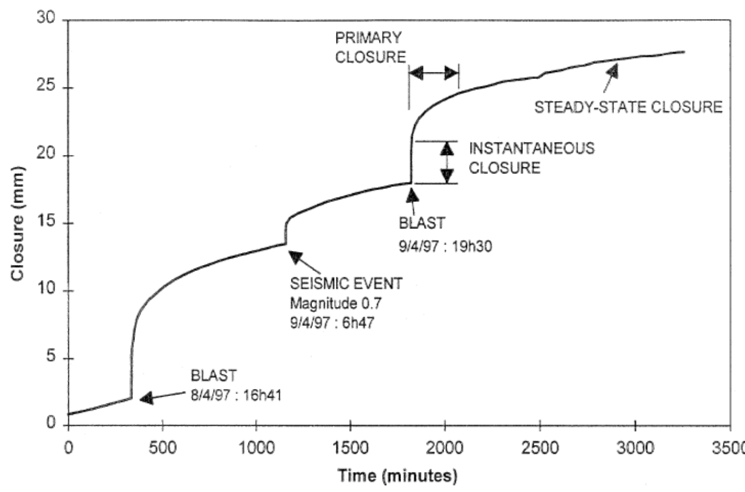


Fig. 5. Typical time-dependent stope closure of the Ventersdorp Contact Reef at Western Deep Levels Mine. This was for a closure station at a distance of 8.7 m from the face

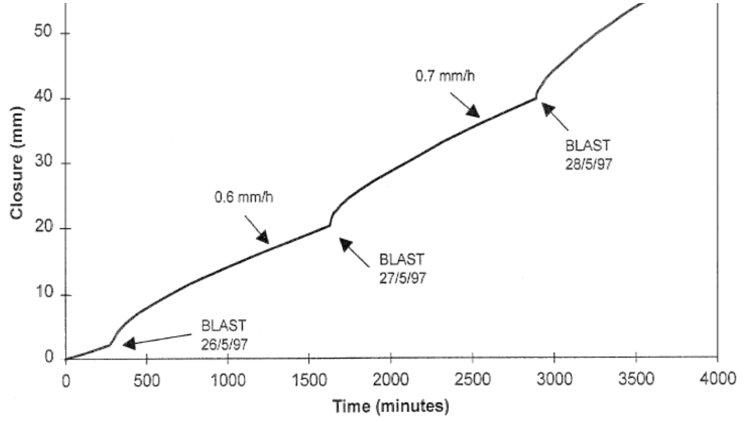


Fig. 12. Closure measurements at Hartebeestfontein Mine for a larger distance to face than that in Fig. 11. The instrument was 14.2 m from the face before the blast on 26/5/97

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1.2a Time dependency:

Effect of Preconditioning

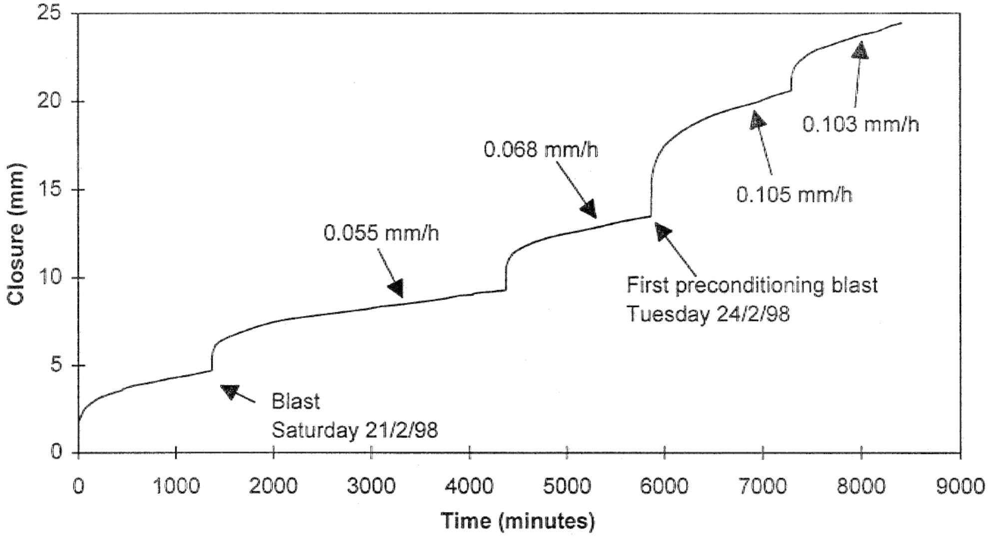


Fig. 23. The effect of preconditioning on the time-dependent closure of a stope in the Ventersdorp Contact Reef. The values indicated in the figure are the steady-state closure rates and were calculated for the periods of 800 minutes after the blast until the next blast occurred. The instrument was 7.2 m from the face at the beginning of this data set and 10.5 m from the face after the last blast in the figure

Malan's Conceptual model

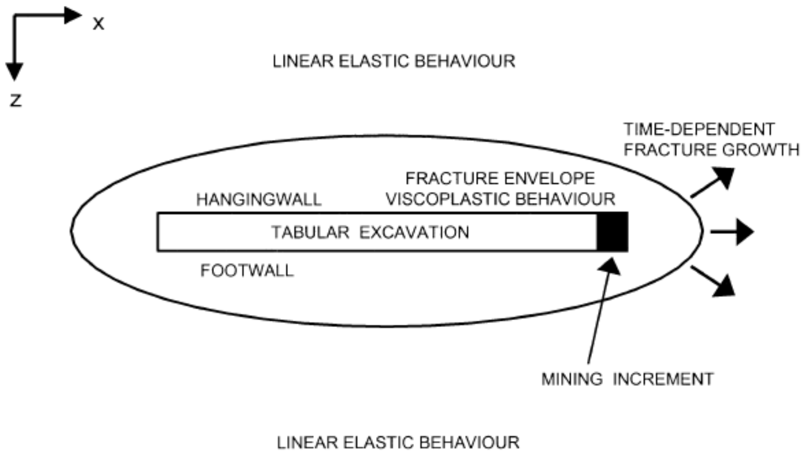


Fig. 13. Conceptualization of the fracture zone surrounding tabular excavations (section view) and time-dependent extension of this zone following a mining increment. The coordinate system is similar to that in Fig. 1, with the y-direction out of the plane of the page

Malan. F.D , Time-dependent Behaviour of Deep Level Tabular Excavations in Hard Rock. Rock Mech. Rock Engng. (1999) 32 (2), 123-155

After (Malan,1999)

1.2b Stress factor

SF = σ/σ_P >0.95

SF = σ/σ_P >0.6

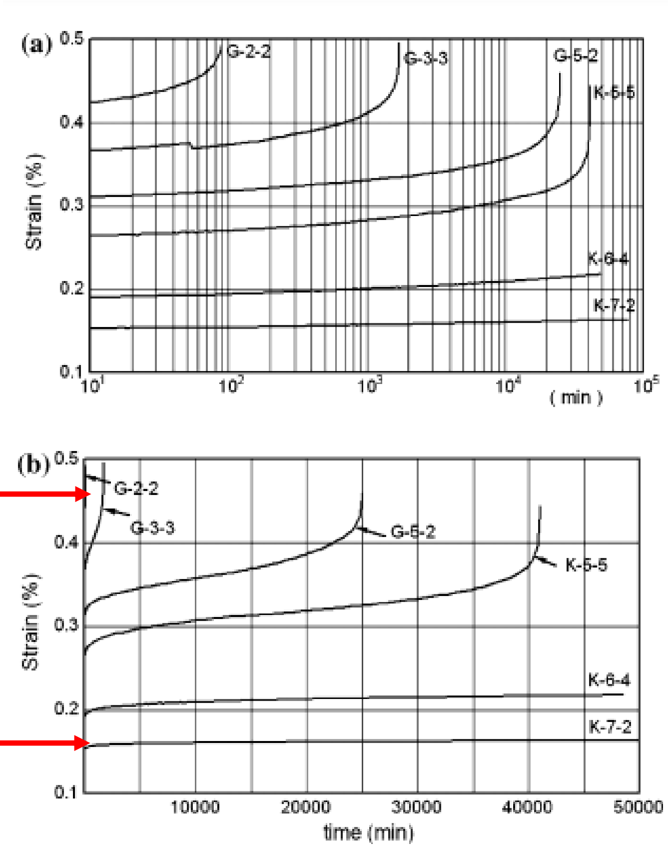


Fig. 5 Uniaxial compression creep response of Oya tuff (modified from Ito and Akagi 2001): **a** plot of experimental response on logarithmic scale, **b** plot of experimental results on linear scale

ISRM Suggested Methods for Determining the Creep Characteristics of Rock

Pre-load closer to peak strength, results in faster time to failure i.e. reduced stand-up time.

50,000mins is 35 days.

OYA Tuff

Remember:
0.5% strain is 5mm between d-Exto anchors with a spacing of 1m

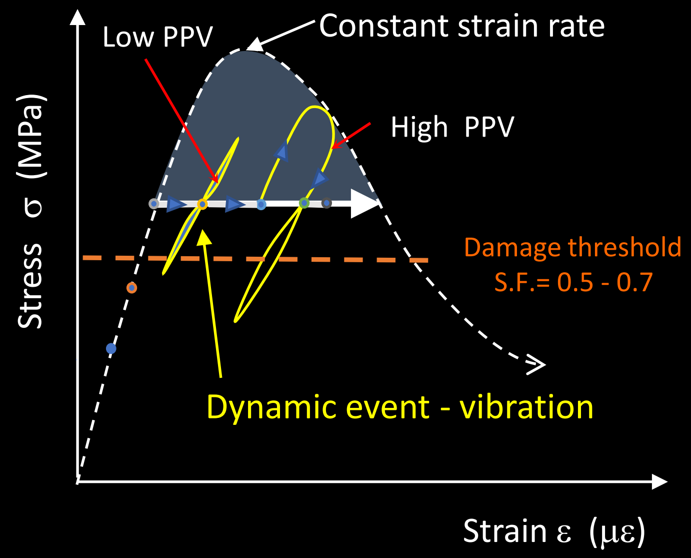
The static stress conditions surrounding an excavation contribute to the level of damage caused by dynamic loading of a rock mass. Dynamic loading potentially adds to the level of static loading in a rock mass.

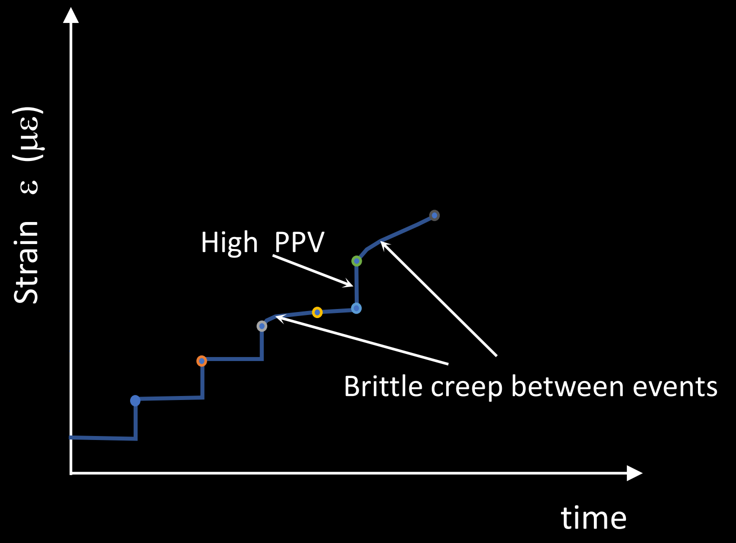
Kaiser et al.(1996) note that for even small seismic events (Richter ~ +1), stress change near excavation surfaces may be up to 20MPa, with stress changes up to 50 MPa for large events (Richter ~ +3)

Stress-Strain space:

When mining drives the rock mass above the damage threshold, time dependent deformations will be measured. When dynamic events such as blasts and seismic events interact with excavations, rock mass will be instantantly loaded resulting in the measurement of permanent deformation associated with micro damage events.

How the damage threshold varies with strain is unknown. Is it flat?





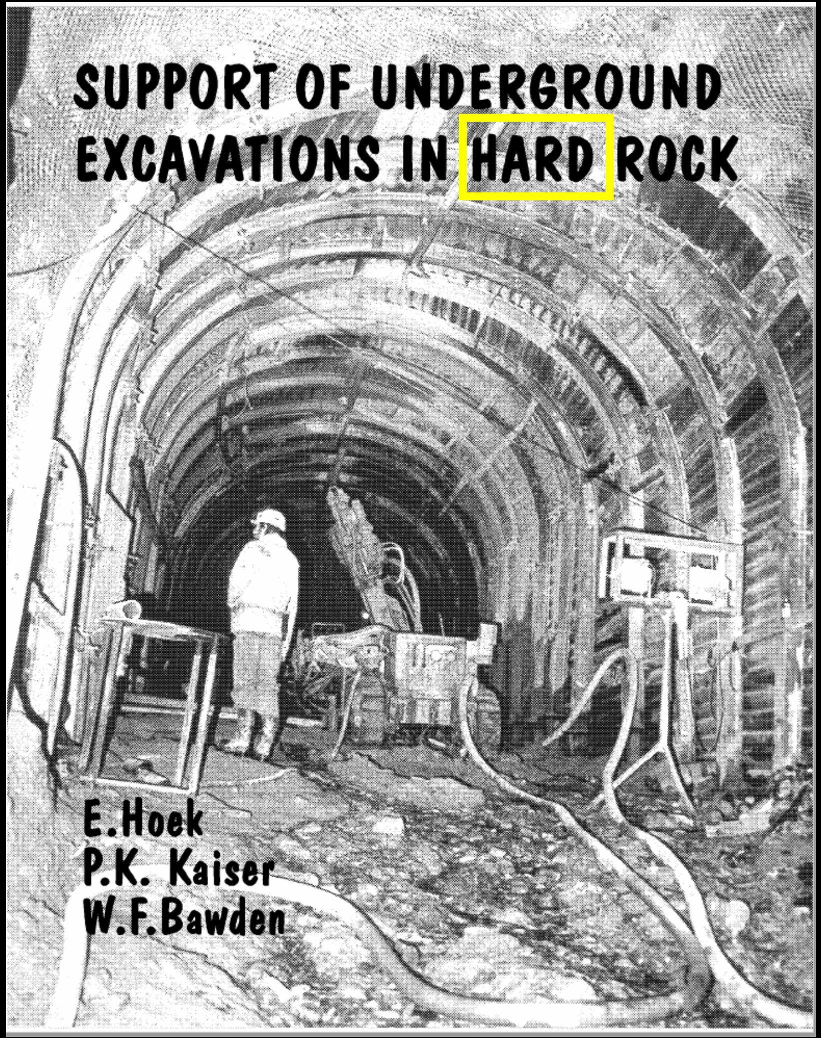
Footnote: Time- dependency discussion

HARD

A justification for dismissing any consideration of the effect of time dependent processes.

p.29 In designing support for hard rock excavations it is prudent to assume that the stability of the rock mass surrounding the excavation is not time-dependent.

- Necessary in order to embrace elastic or elasto-plastic models.
- Approach feasible for civil projects where sufficient ground support is installed to stop convergence. Not an economically viable strategy for mining.
- Time is of the very essence of mining, service-life of excavations.
- Time dependency becomes more important with depth (25 years later – mines are deeper)
- Without proper consideration of time "prediction" is impossible.



Monitoring Ground Support Workshop

1. **Temporal Plot:** *Displacement Velocity + Acceleration*

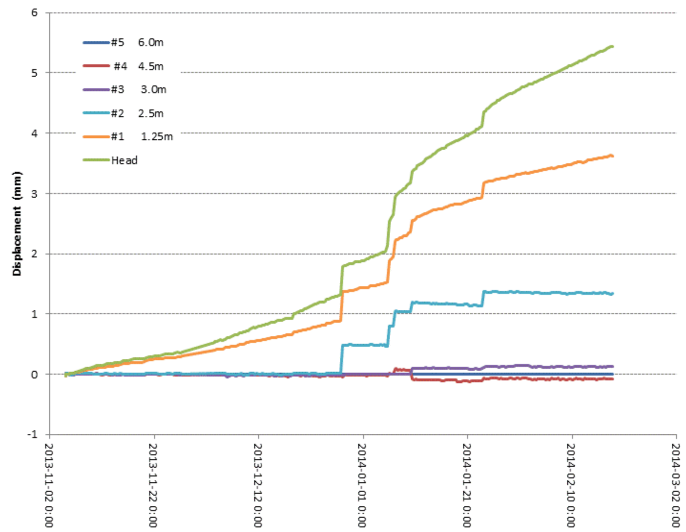
   1.1. Events:
   - a. Blasting Events
   - b. Seismic Events

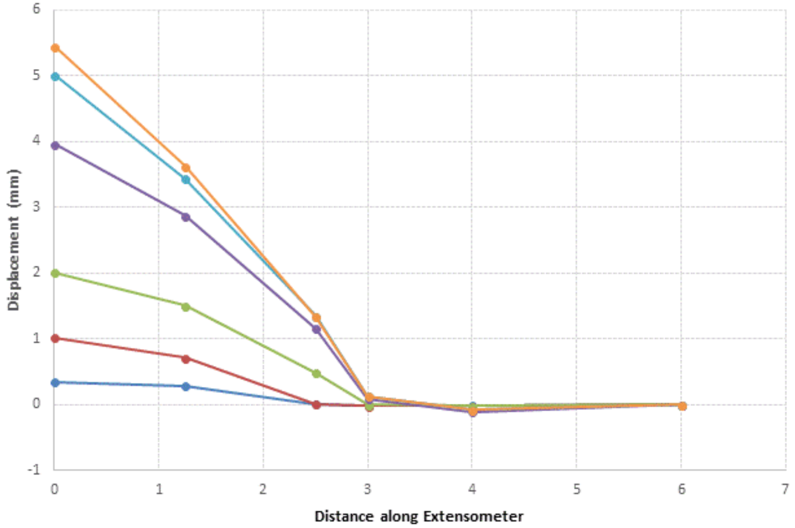
   1.2. Time dependency:
   - **a. Brittle Creep**
   - **b. Stress Factor(s/s_F)**

2. **Spatial Plot:** *Strain, Strain rate*

   2.1 Strain.
   2.2. Rock Support Condition.
   2.3. Localization

3. Pulling it all together into an **Excavation Management Solution**

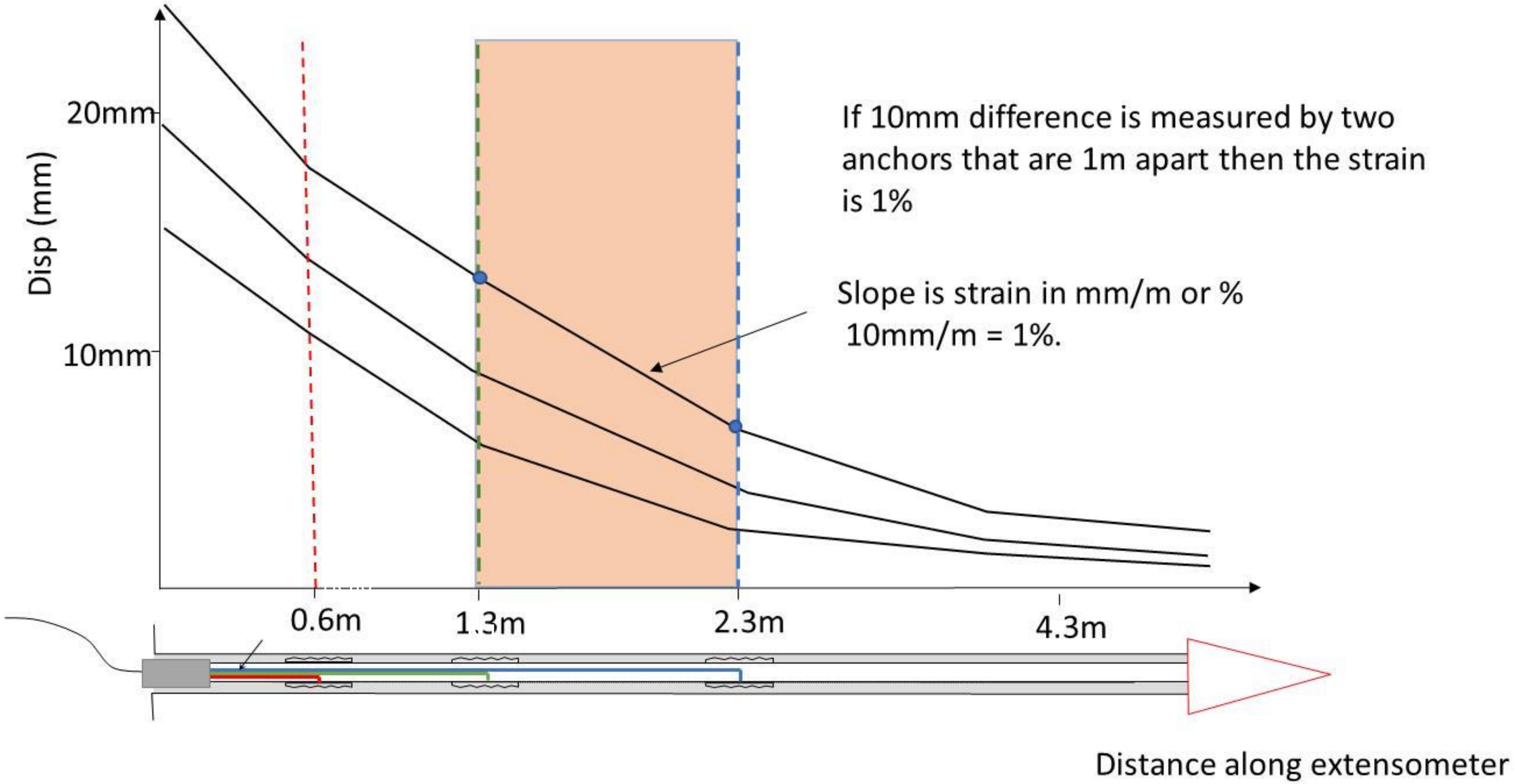




YieldPoint *Sensing the future*

Outline of Presentation

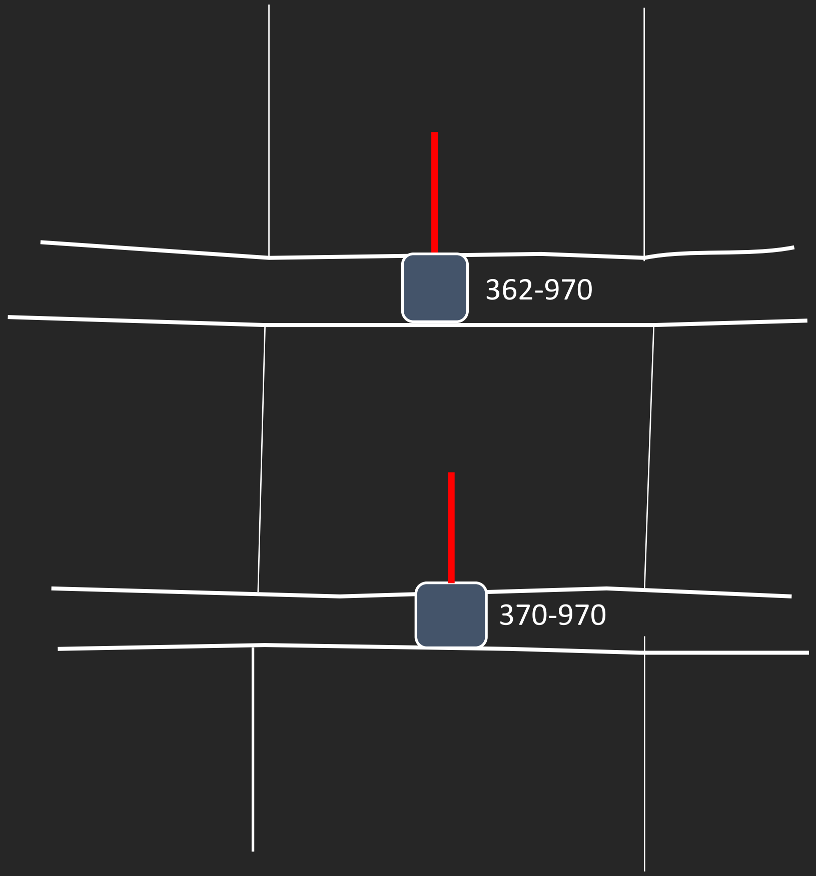
How do we calculate strain from an MPBX?

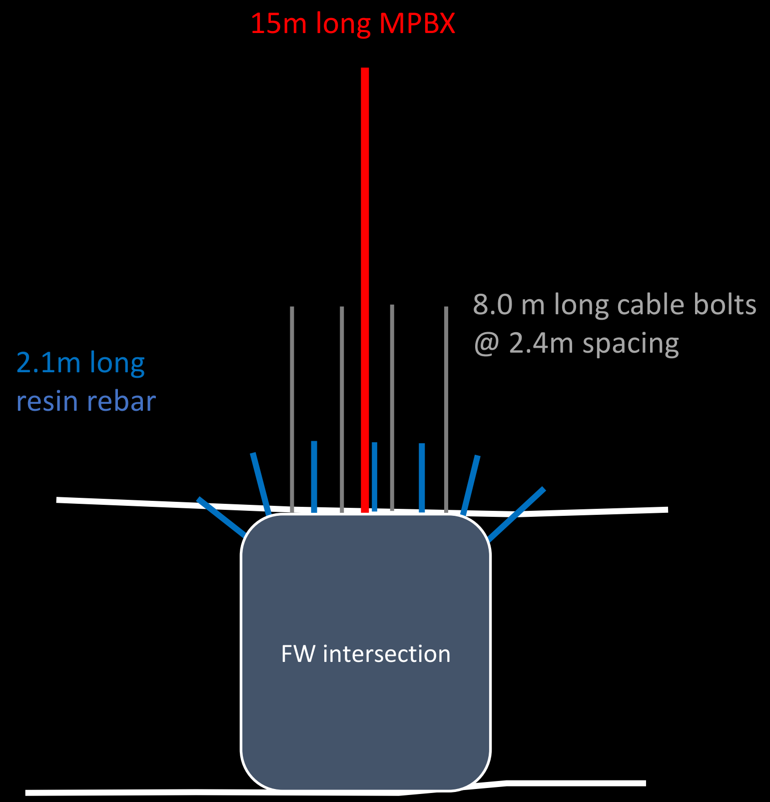


If 10mm difference is measured by two anchors that are 1m apart then the strain is 1%

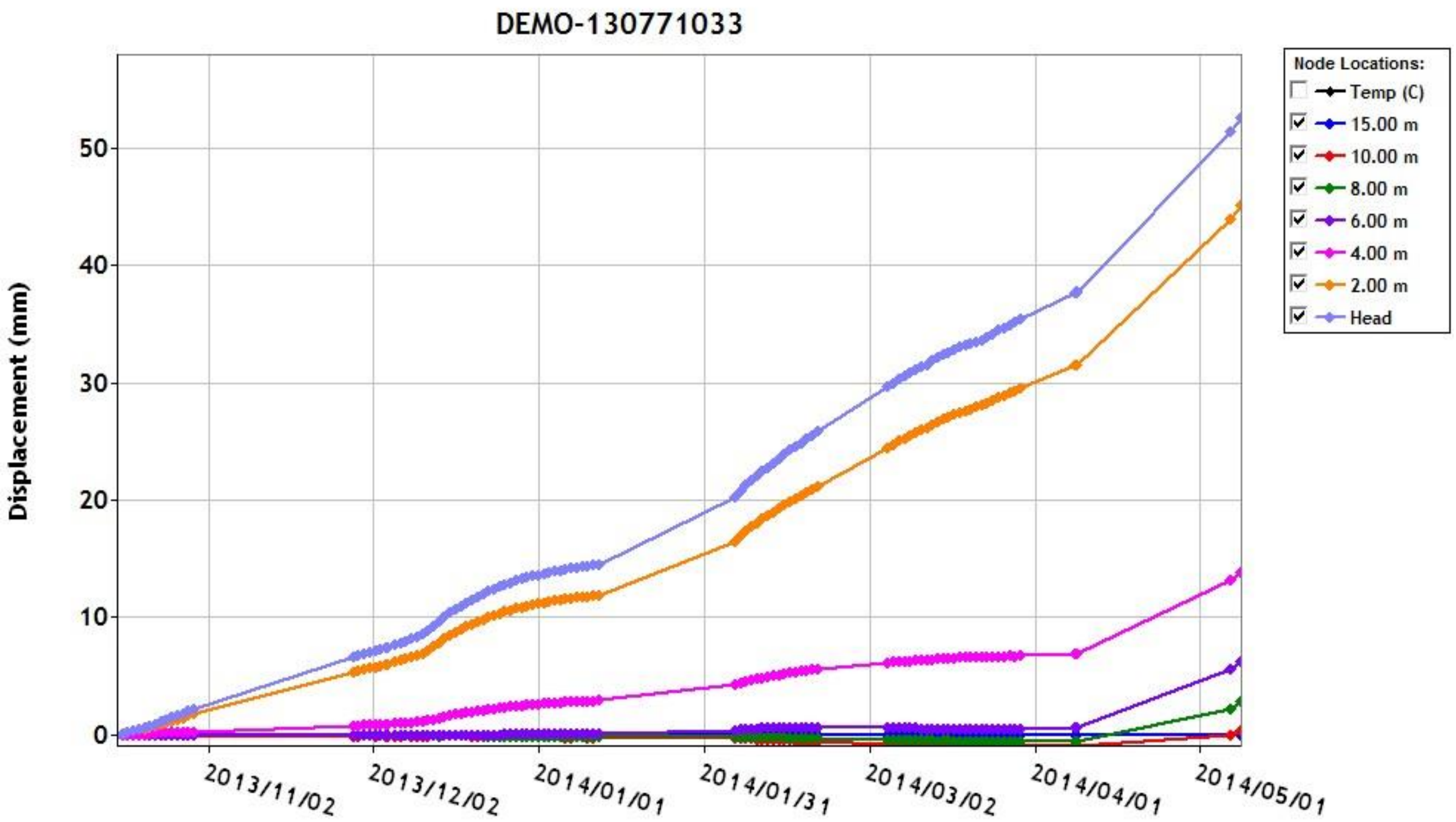
Slope is strain in mm/m or %
10mm/m = 1%.

Case Example: Using MPBX to monitor Ground Reinforcement

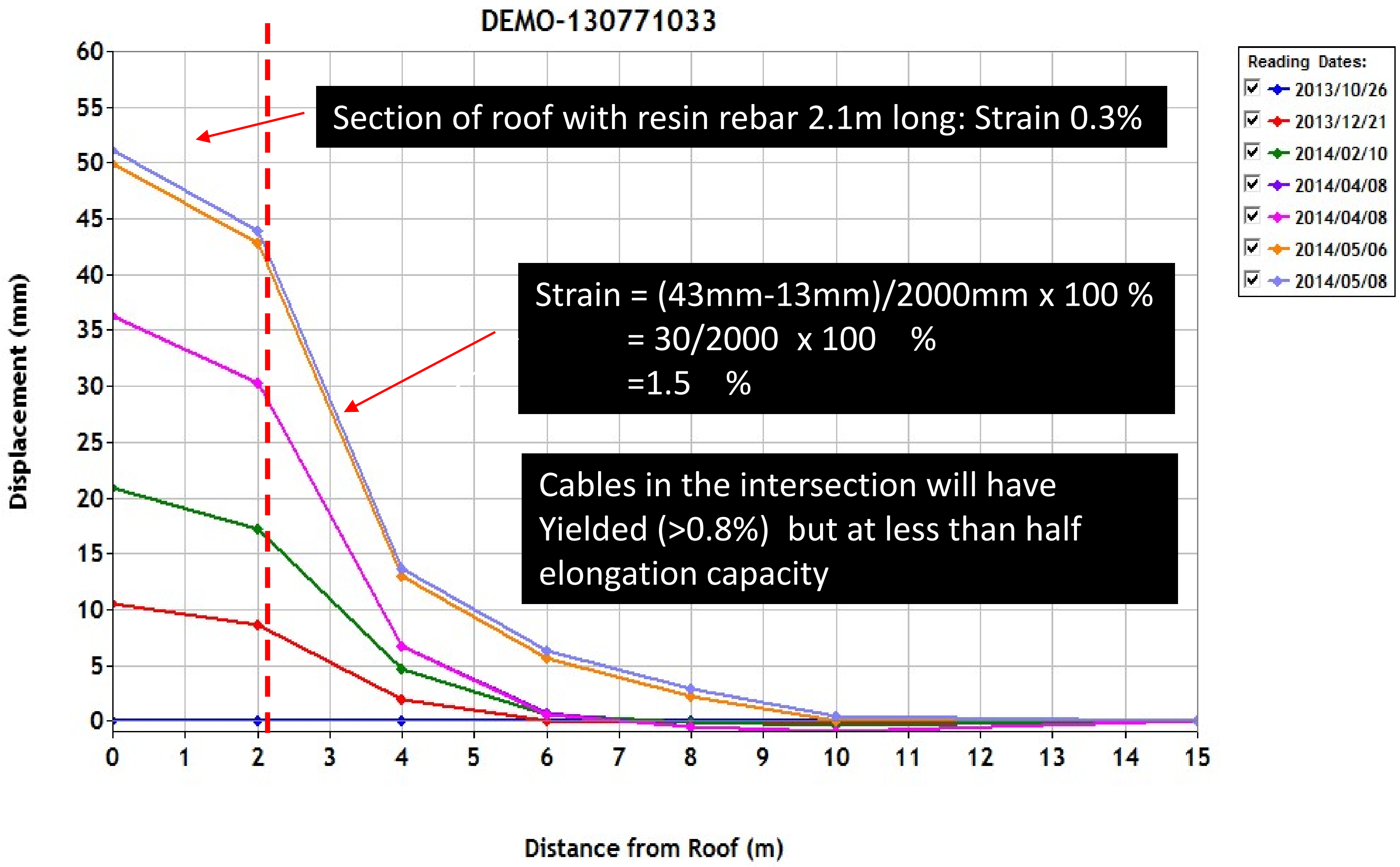




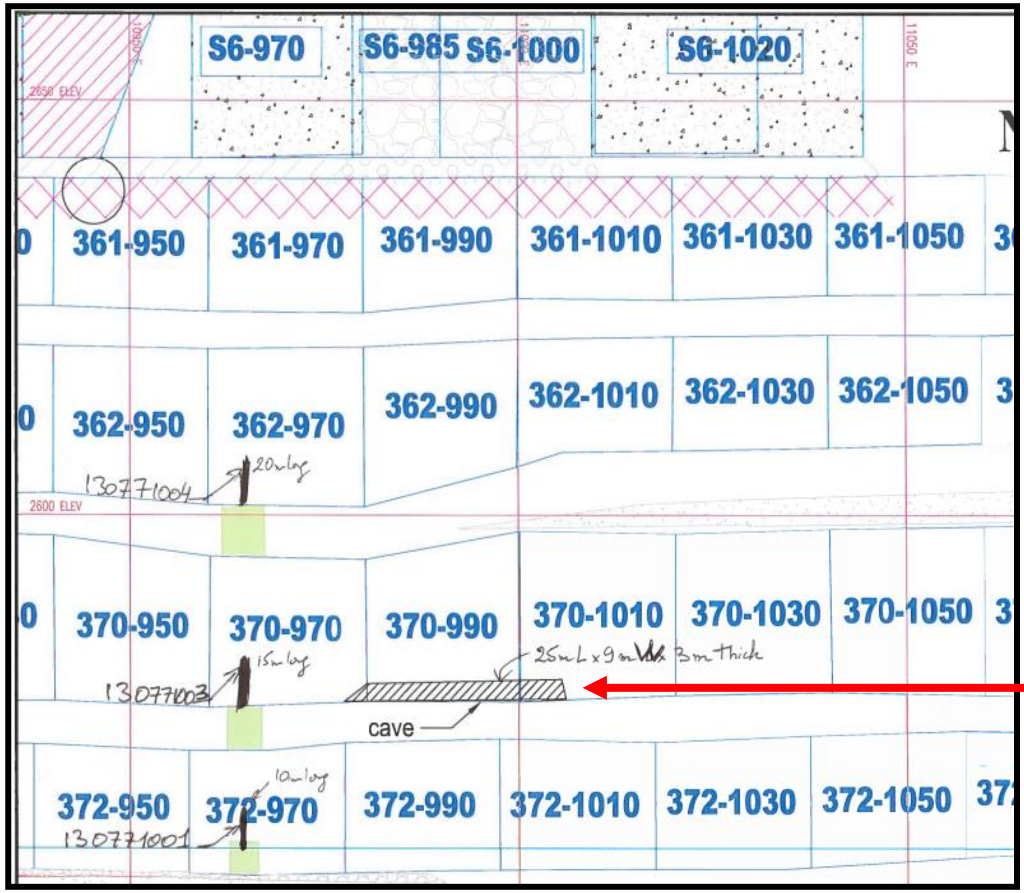
Case Example: Using MPBX to monitor Ground Reinforcement



Case Example: Using MPBX to monitor Ground Reinforcement

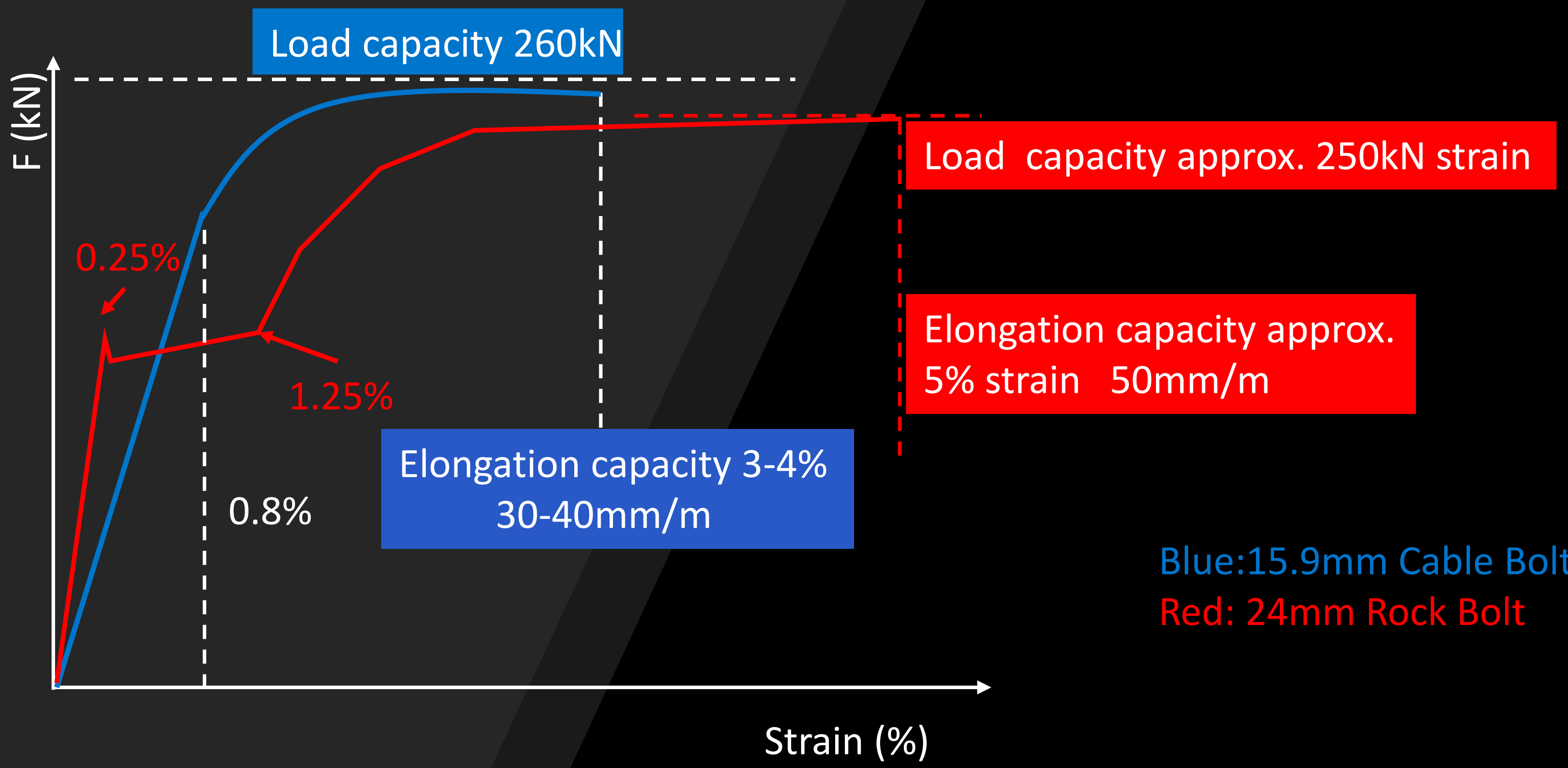


Case Example: Using MPBX to monitor Ground Reinforcement



25m Long x
9m wide x
3m thick FOG

2.2 Spatial/Rock Support Safety Margin



Using MPBX to access Reinforcement Safety Margin: Cable Bolt and Rock Bolt

Monitoring Ground Support Workshop

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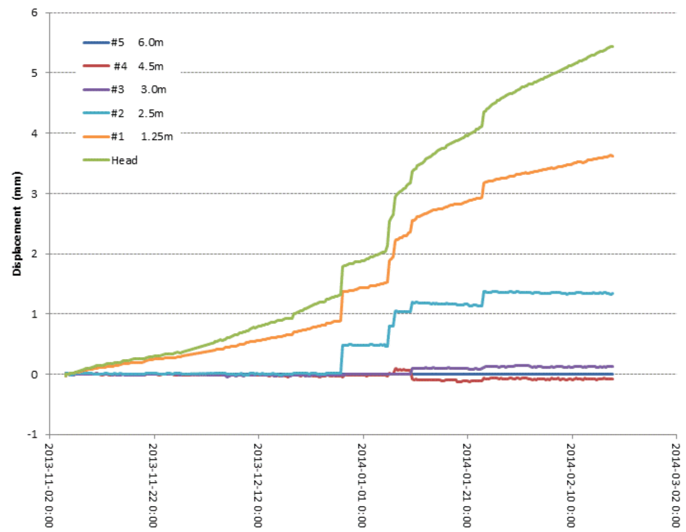
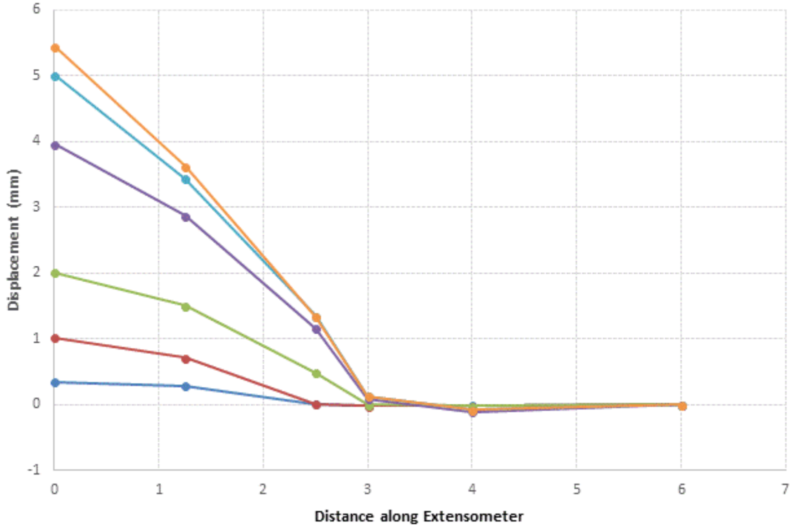
   Excavation Management Solution





YieldPoint Sensing the future

Outline of Presentation

3. Putting it all together:
Excavation Monitoring Solution

3.1 Instruments
d-Exto, d-Cable, d-SDDB
d-PPV Event monitor

3.2 Low cost telemetry
BluPoint, 1 for 1 radios

3.3 VantagePoint
Aggregation, Visualization

3.4 +VantagePoint *pron AdvantagePoint*
Analytics + AI model

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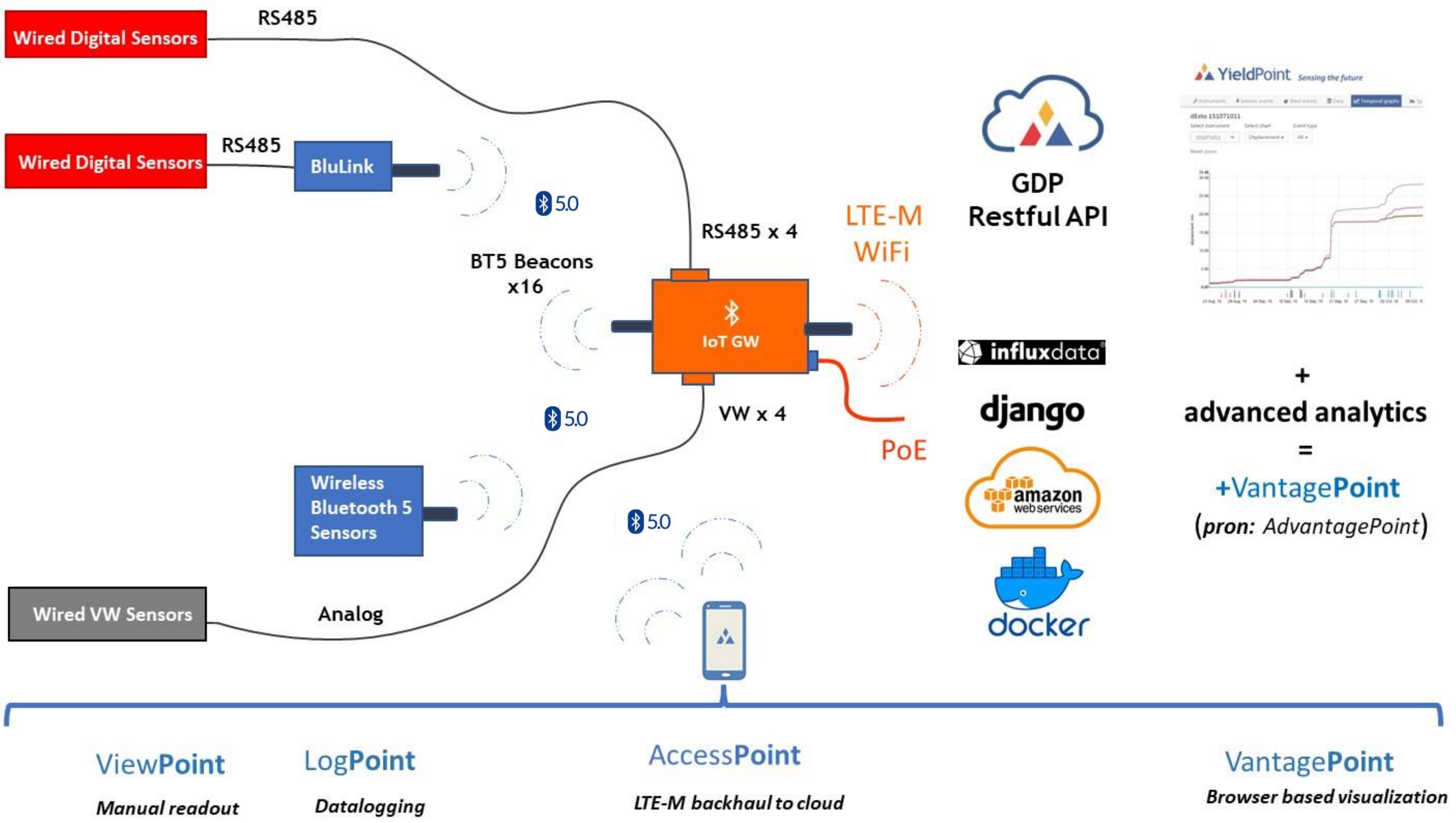
Excavation management solution



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The YieldPoint Ecosystem

Excavation management solution

dExto - Hard Rock: Grouted borehole extensometers

Range: up to 250mm at 10µm resolution.

Length: up to 40m/140ft. Diameter 25mm/1”.

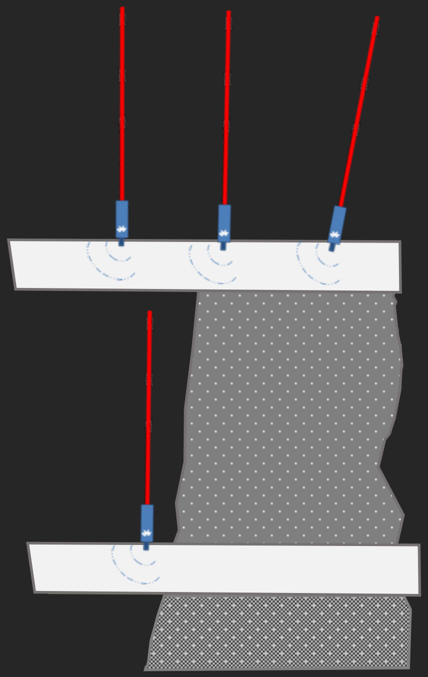
Head length: 40 to 50cm/16 to 20”.

Up to 6 anchor points.

Pre-calibrated, ready to install.

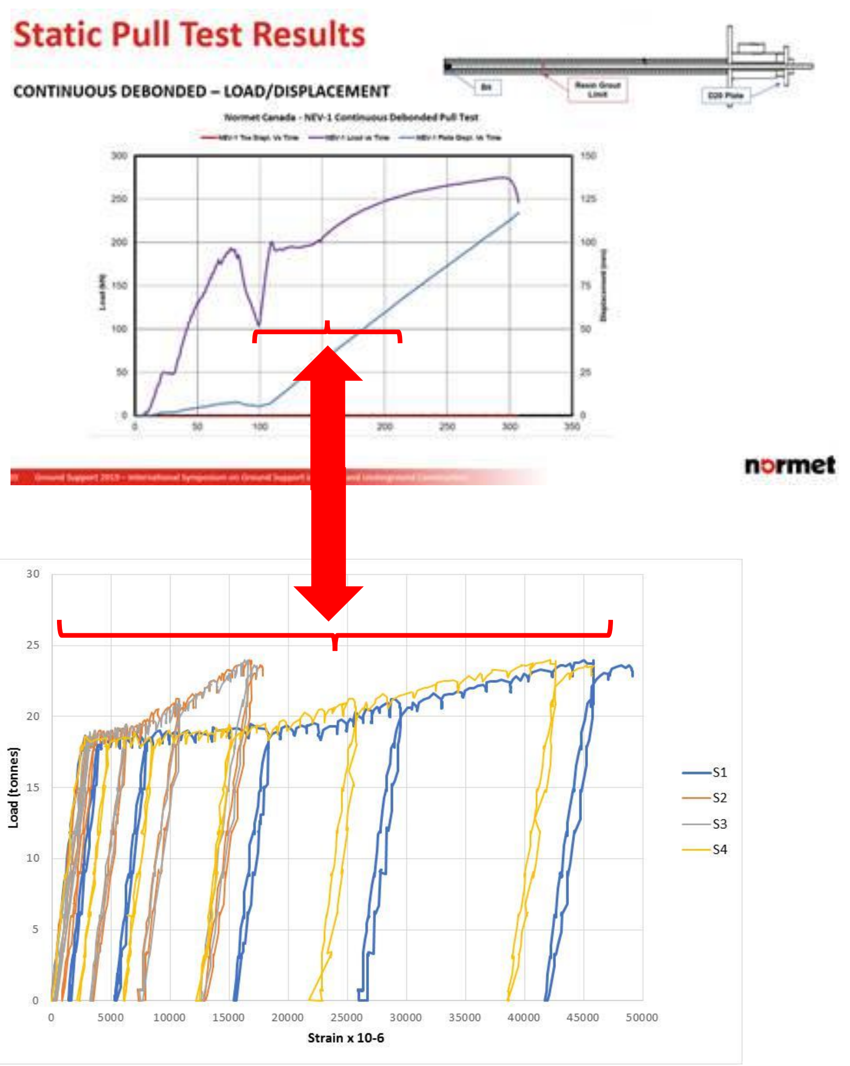
Excavation management solution

The extensometer is a 6-point borehole extensometer with measurement resolution of 0.1mm and stroke length up to 300mm. Integration includes a grout hose, a breather tube and a foaming tube which greatly simplifies the installation procedure. The diameter of the head is 57mm or 2.25” and the device is designed to be installed in 63mm or 2.5” boreholes (ask about smaller diameters).



Normet developed the SDDB® (Self-Drilling Dynamic Bolt), designed for squeezing ground and broken rock mass conditions where traditional bolts are difficult to install.

YieldPoint has instrumented the SDDB®.



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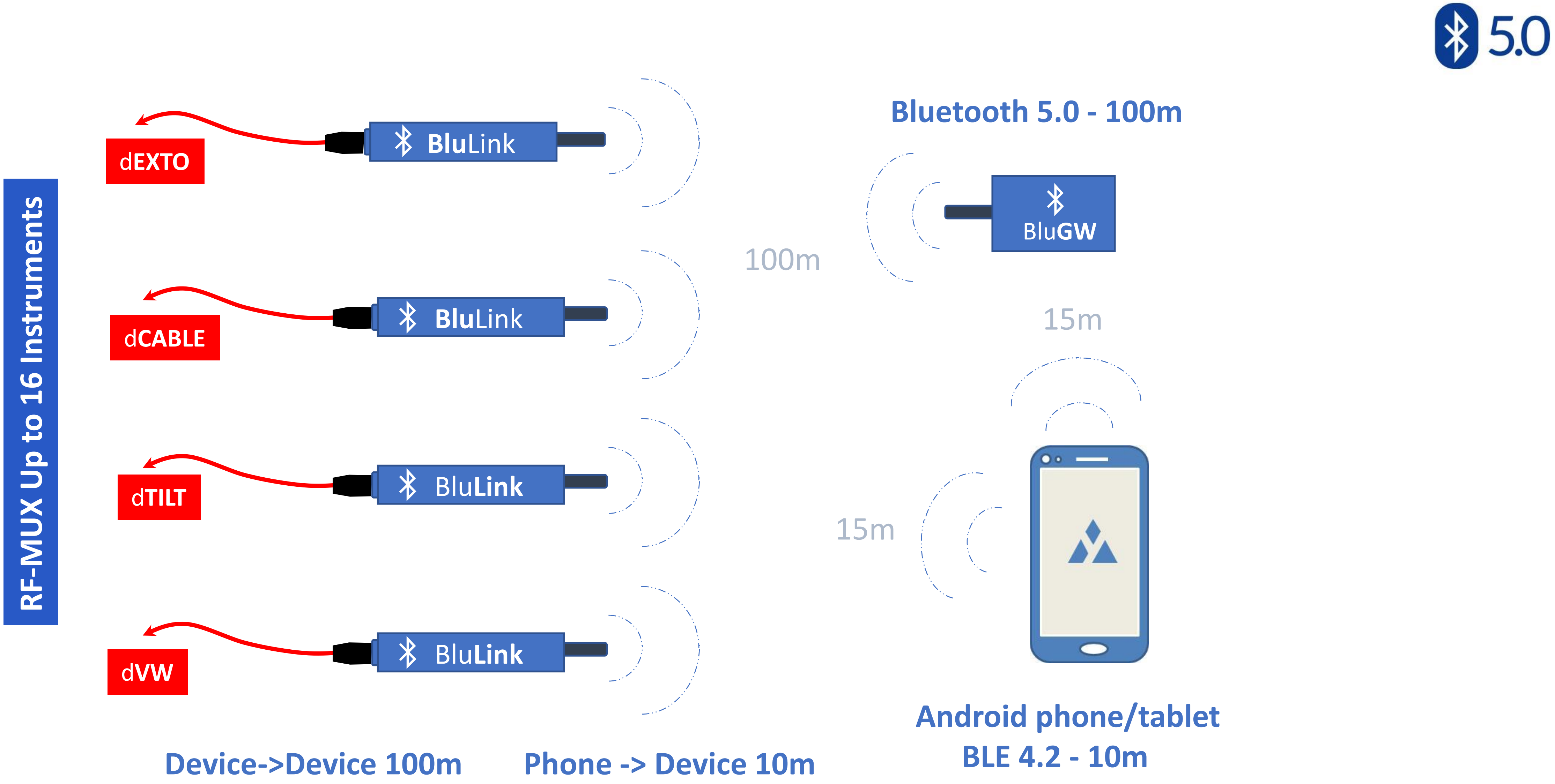
dSDB/dSDDB

2 models:

(i) Based on 4.5Hz geophone
(ii) Based on low noise tri-axial accelerometer

- Bluetooth enabled.
- Stores up to 30,000 events
- Transmits events over Bluetooth 5 to networked BluGateway
- Exto and PPV data uploaded to VantagePoint

Excavation management solution



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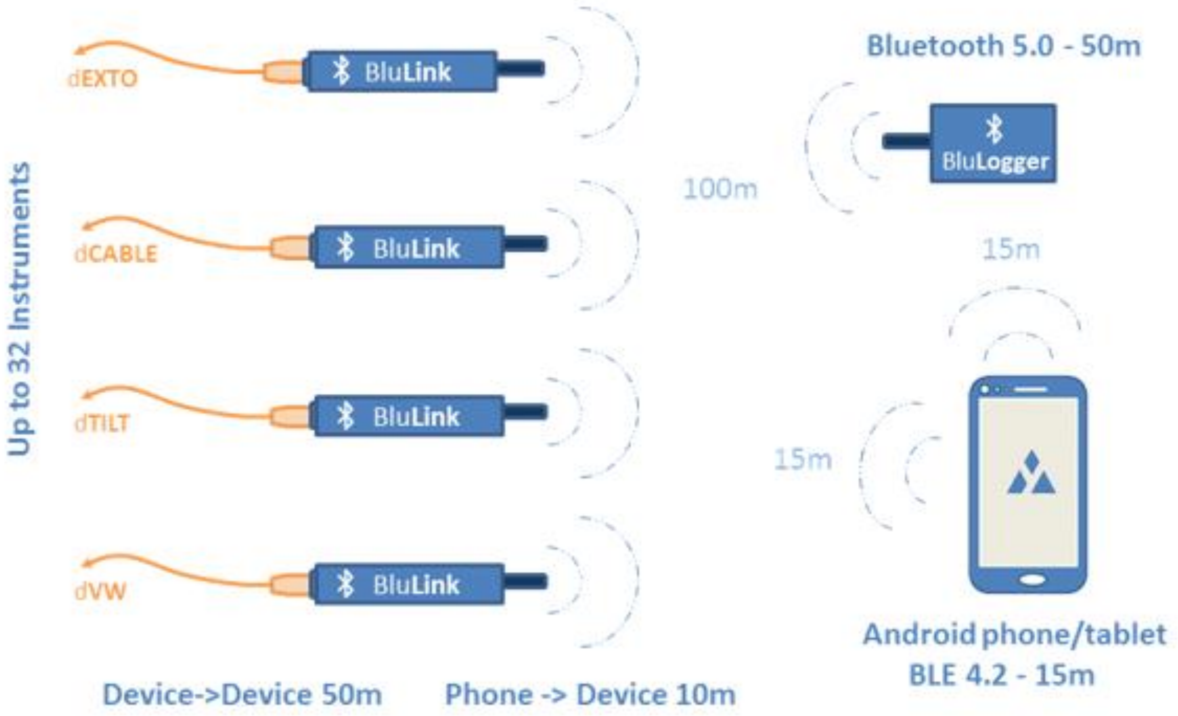
Leadwire replacement



BluLink loggers turn any YieldPoint instrument into a data logger with Bluetooth BLE5 capability. 30,000 readings saved, 50 to 200m transmission range, adjustable frequency. BluPoint Android application. Sends data to BluGateway for networking.

The BluLink-S is fully encapsulated and will operate indefinitely underwater.

YieldPoint *Sensing the future*

BluLink-S (sealed)

Excavation management solution

YieldPoint introduces BluPoint - a user friendly method to network clusters of geotechnical instruments without leadwires - changes the rules because the physical hardware actually costs less than for a hardwired solution.

BluPoint features include:

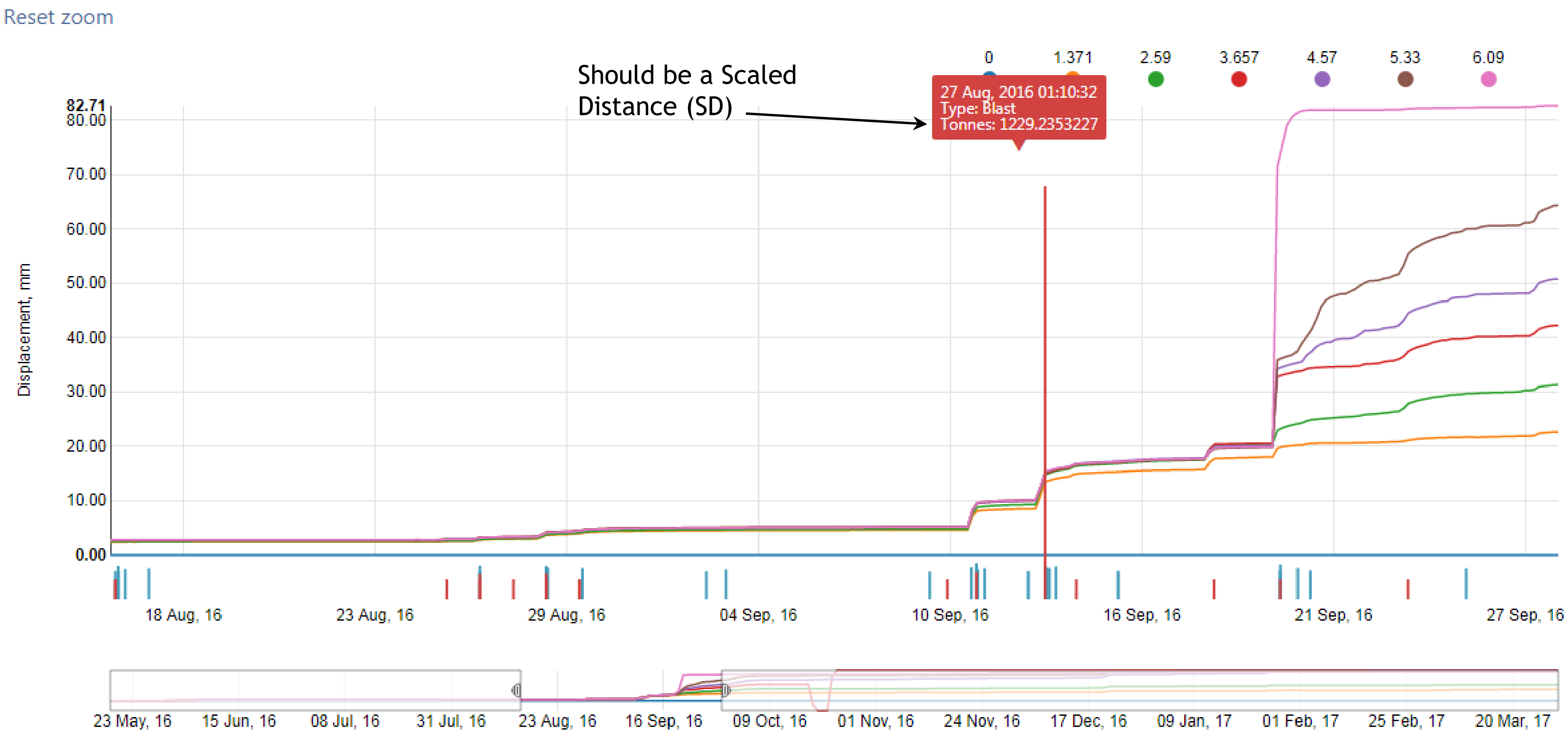
(i) Extended range: Reliable up to 100m
(ii) Android phone/tablet access
(iii) Low power, Battery powered.
(iv) 4 x the range of BLE4.
(v) User friendly BluLoggers for arrays of wired/wireless instruments
(vi) BluGateways enabling WiFi, LTE-M data backhaul
(vii) Cloud data platform and analytics
(viii) Operates in star configuration
(ix) Very low cost

5.0

YieldPoint *Sensing the future*

BluPoint Solution 2022

Excavation management solution



Based on ultra-fast "time series" database. Browser enabled.

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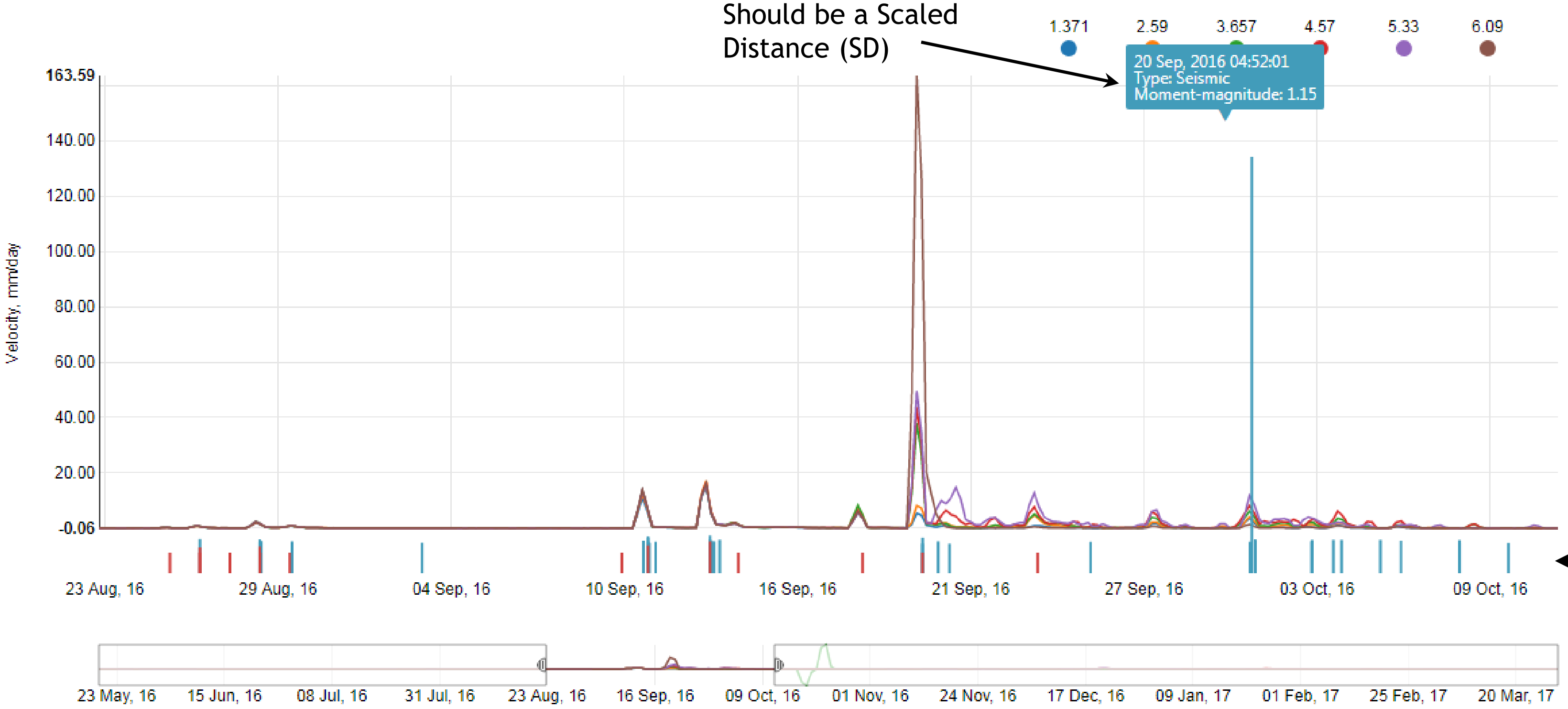
VantagePoint

Should be a Scaled Distance (SD)



Operations events

Based on ultra-fast “time series” database. Browser enabled.

Analytics layer. Train empirical models to recognize the patterns between Mining Operation and Excavation Damage.

Down-size **macro** damage literature derived from 2 main bodies of work:

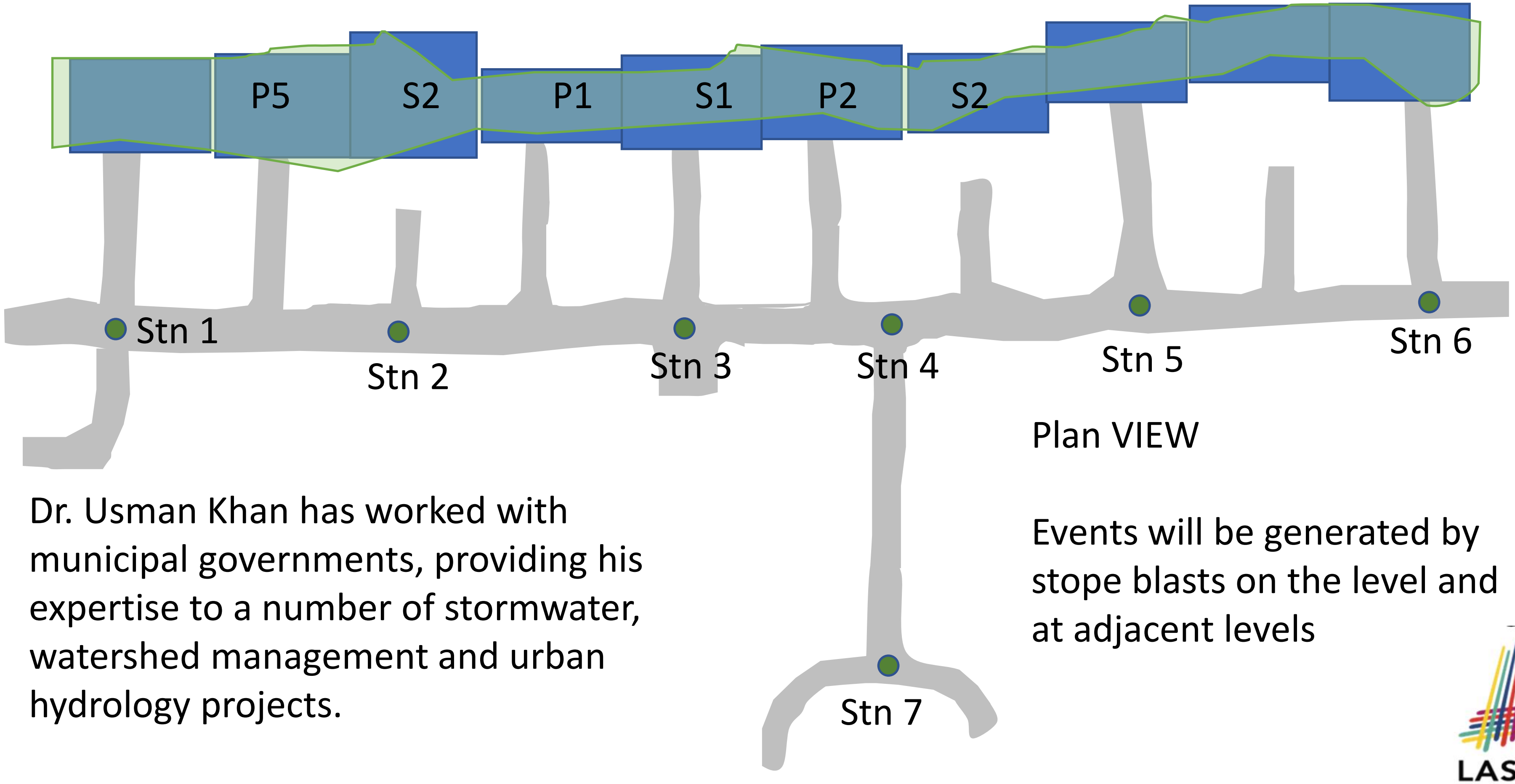
(i) Canadian Rock burst handbook GRC Laurentian University, ON

(ii) University of Western Australia. Heal and Potvin dataset of major rock burst related failures. Introduce concept of

Excavation Vulnerability Potential

Analytics layer. Train empirical models to recognize the patterns between mining Operation and excavation micro-damage.

Systematic layout for prospective experiment



Plan VIEW

Events will be generated by stope blasts on the level and at adjacent levels

Dr. Usman Khan has worked with municipal governments, providing his expertise to a number of stormwater, watershed management and urban hydrology projects.

Dr. Matt Perras

For macro damage due to rock bursts

Big data AI Models should adopt the approach taken for macro-damage

EVP – Excavation Vulnerability Potential

$$EVP = \frac{E_1}{E_2} \times \frac{E_3}{E_4}$$

$\frac{E_1}{E_2}$	Damage initiation factor
$\frac{E_3}{E_4}$	Depth of failure factor

E_1 – Stress Factor (SF) related to time dependency

E_2 – The energy capacity of the installed support system Note: should we distinguish between static and dynamic energy? **(Strain around excavation)**

E_3 – The excavation Span in m (Hydraulic radius or Excavation Radius Factor)

E_4 – The presence or otherwise of a seismically active structure

Heal *et al.* (2006)

Excavation management solution

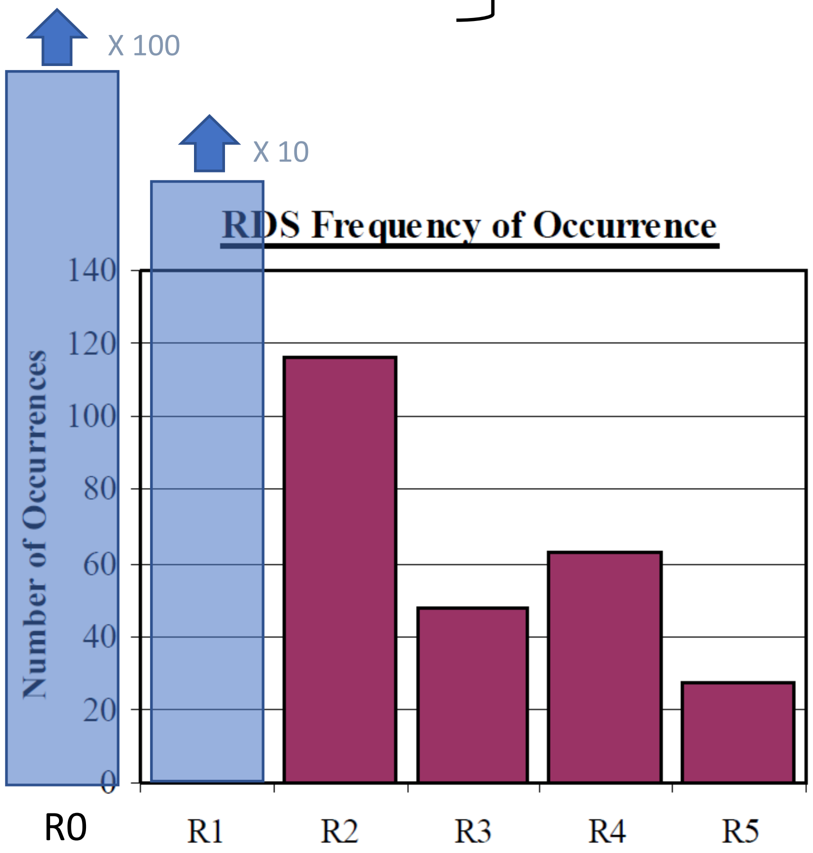
3.4 +VantagePoint : Framework

R1 – No damage, minor loose > 1mm displacement
R0 – Not visually detectable but measured by extensometer <1mm disp

Micro-damage Events

Table 2. Rockburst Damage Scale (RDS) used to assess the case history data.

Rockburst Damage Scale	Rock mass Damage	Support Damage
R1	No damage, minor loose	No damage
R2	Minor damage, less than 1 tons displaced	Support system is loaded, loose in mesh, plates deformed
R3	1-10 tons displaced	Some broken bolts
R4	10-100 tons displaced	Major damage to support system
R5	100+ tons displaced	Complete failure of support system



After Heal(2010)

Excavation management solution

Ultimately, "value" resides in the capability to forecast

"For the first time ever on the final day of the Tournament, tee times were moved up to 7:30 a.m. [EDT], with contestants going off both the first and 10th tees in three-somes,"

2019

MASTERS TOURNAMENT®

@2:27pm

For every tweet using the words "historic" "memorable" "epic" "all-time" "unreal" etc. Remember that today's @TheMasters @PGATour #MastersSunday #Masters #TigerWoods #GreenJacket was ONLY made possible by the SCIENCE OF METEOROLOGY. #WeatherReadyNation

358 2:27 PM - Apr 14, 2019

Weather radar @2:27pm

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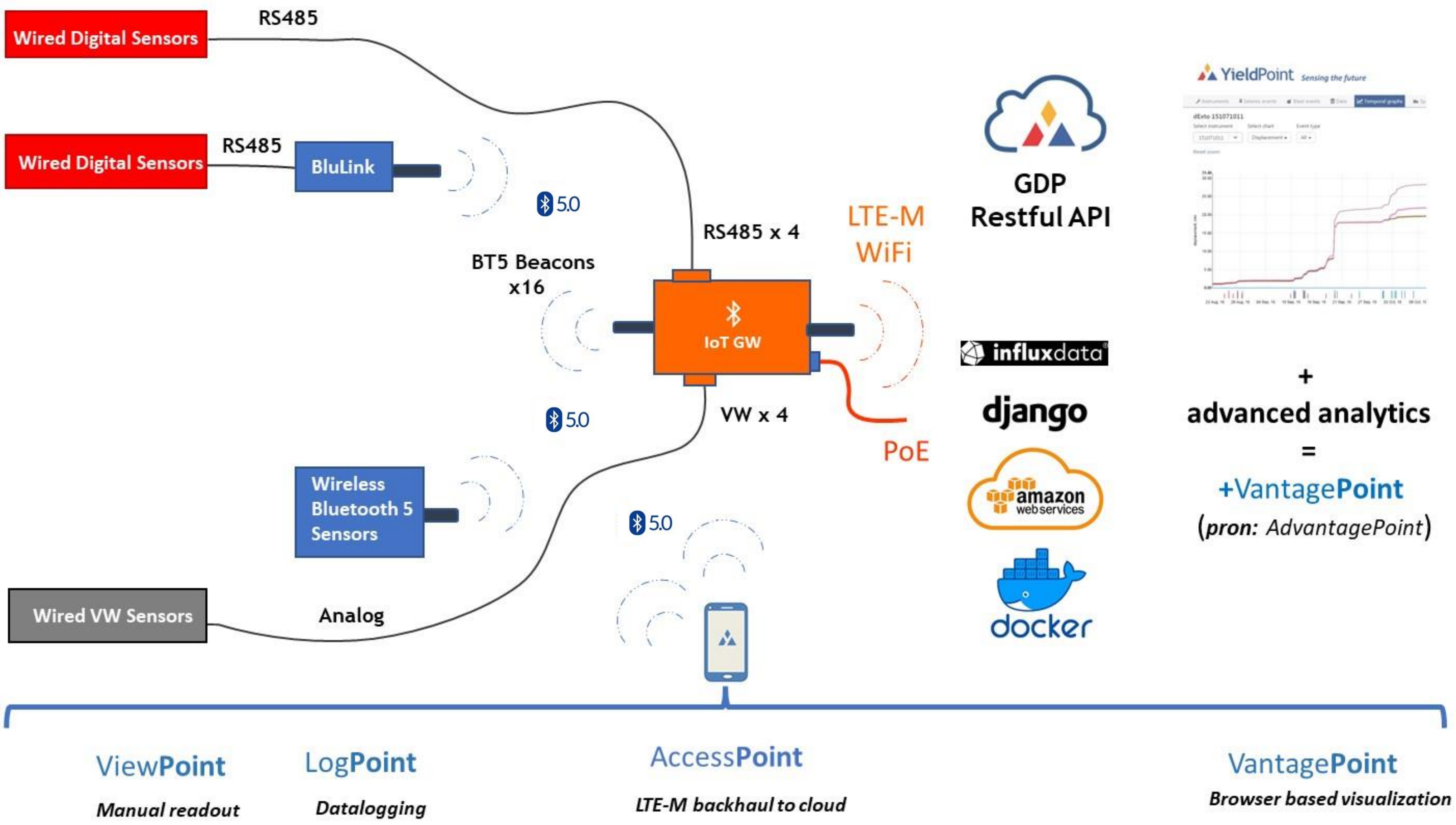
+VantagePoint

The BluPoint Solution - June 2022



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The YieldPoint Ecosystem