The Australian Network of Structural Health Monitoring

8th Annual Workshop

Monash University, Melbourne

Advanced asset health indicators for utility wooden poles

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Utility wood poles health indicators

- **Remaining Strength of the pole**
- **Probability of Failure of the pole**

Assess Condition of the Pole (Calculate Remaining Strength)

- **Non-Destructive Testing (NDT) method**

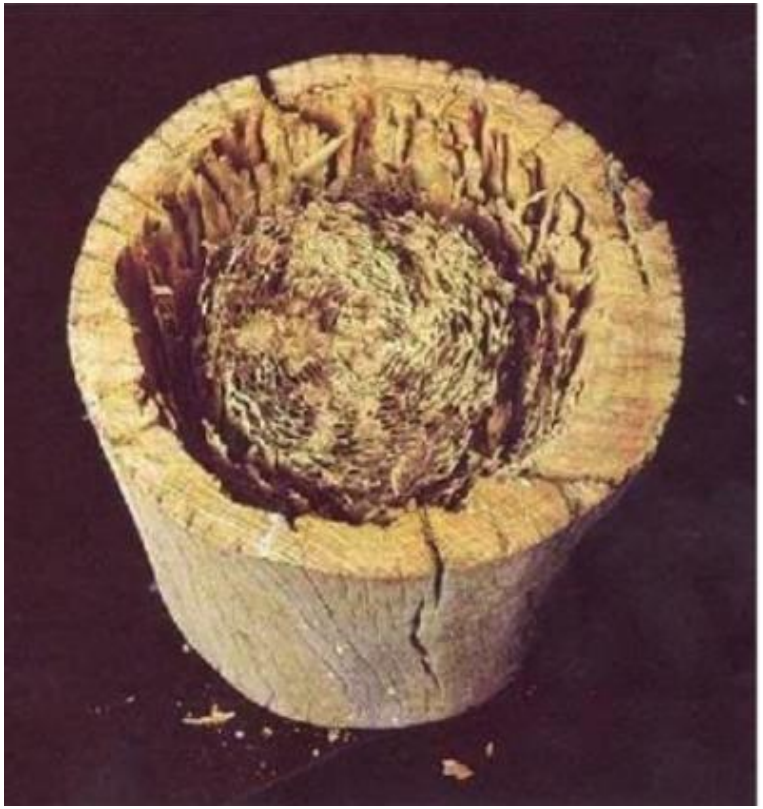
- Pole Radar Unit (Find areas of the pole with compromised wood)

- Pole Tester (Test the pole at the desired cross-section and find Remaining Strength of the pole)

- **Mobile Software Application (Pole Tester)**

Assess Load on the Pole (Calculate Probability of Failure)

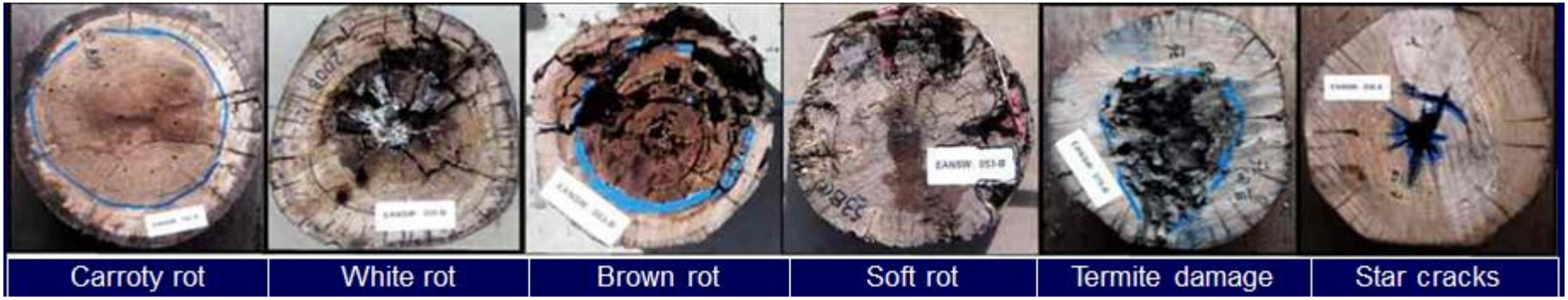
- **Reliability Based Design method**
- **Mobile Software Application (Pole Designer)**

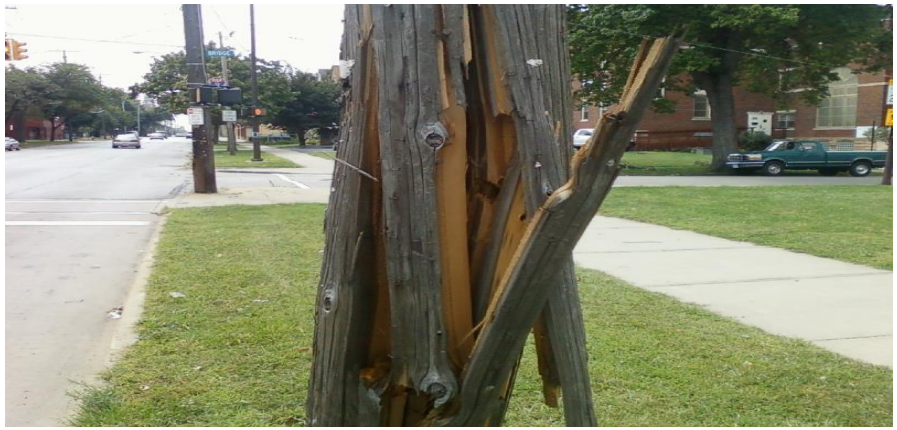


Some of the issues

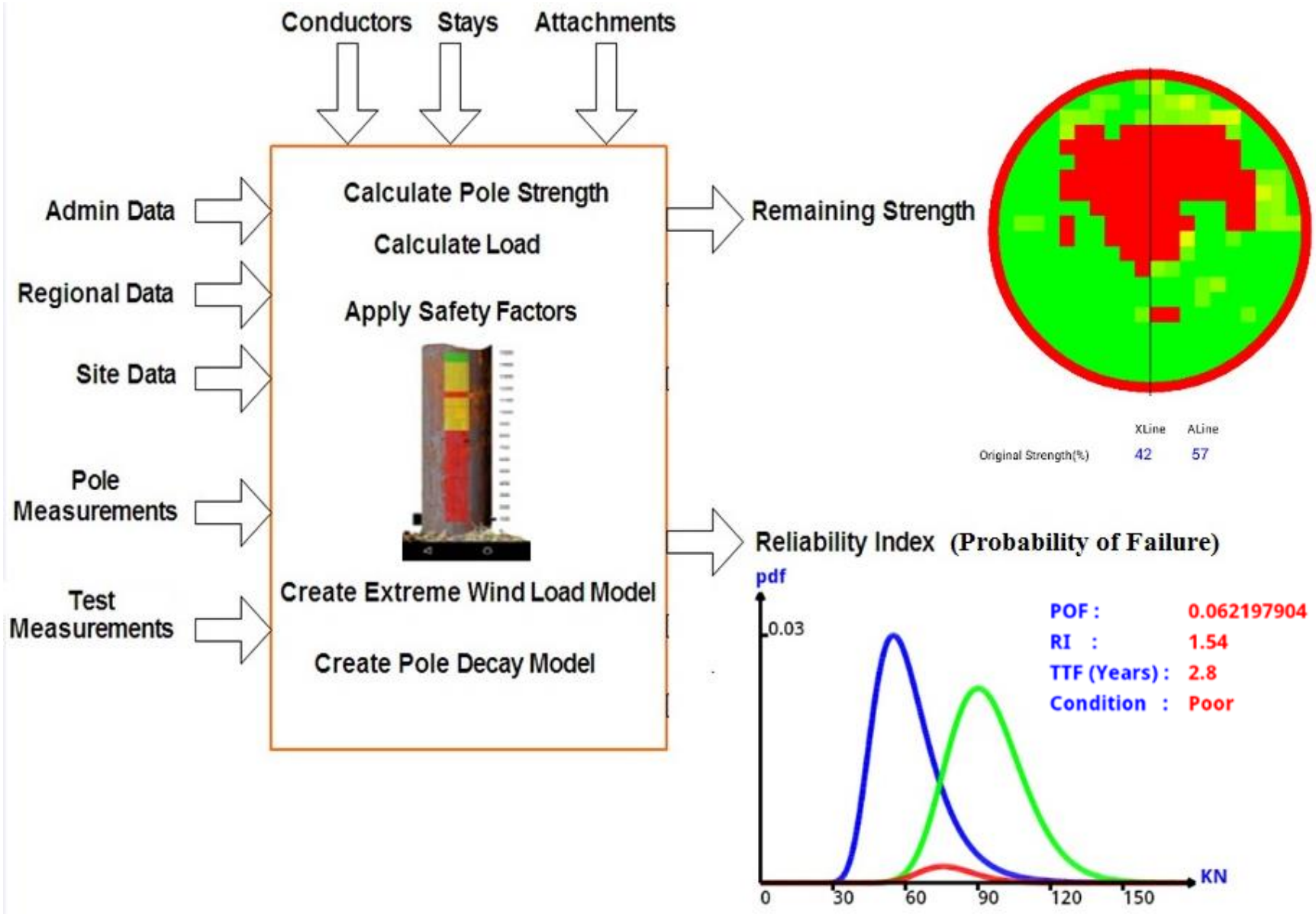
- Wooden poles used for electricity distribution deteriorate with age.
- 70 per cent of the 8.5 million wooden poles in service as part of the electricity distribution infrastructure in Australia are over 35 years old.
- Termite damage to wooden power poles is a huge problem in Australia.

Wooden Pole Internal & External Decay





Utility wood poles health indicators



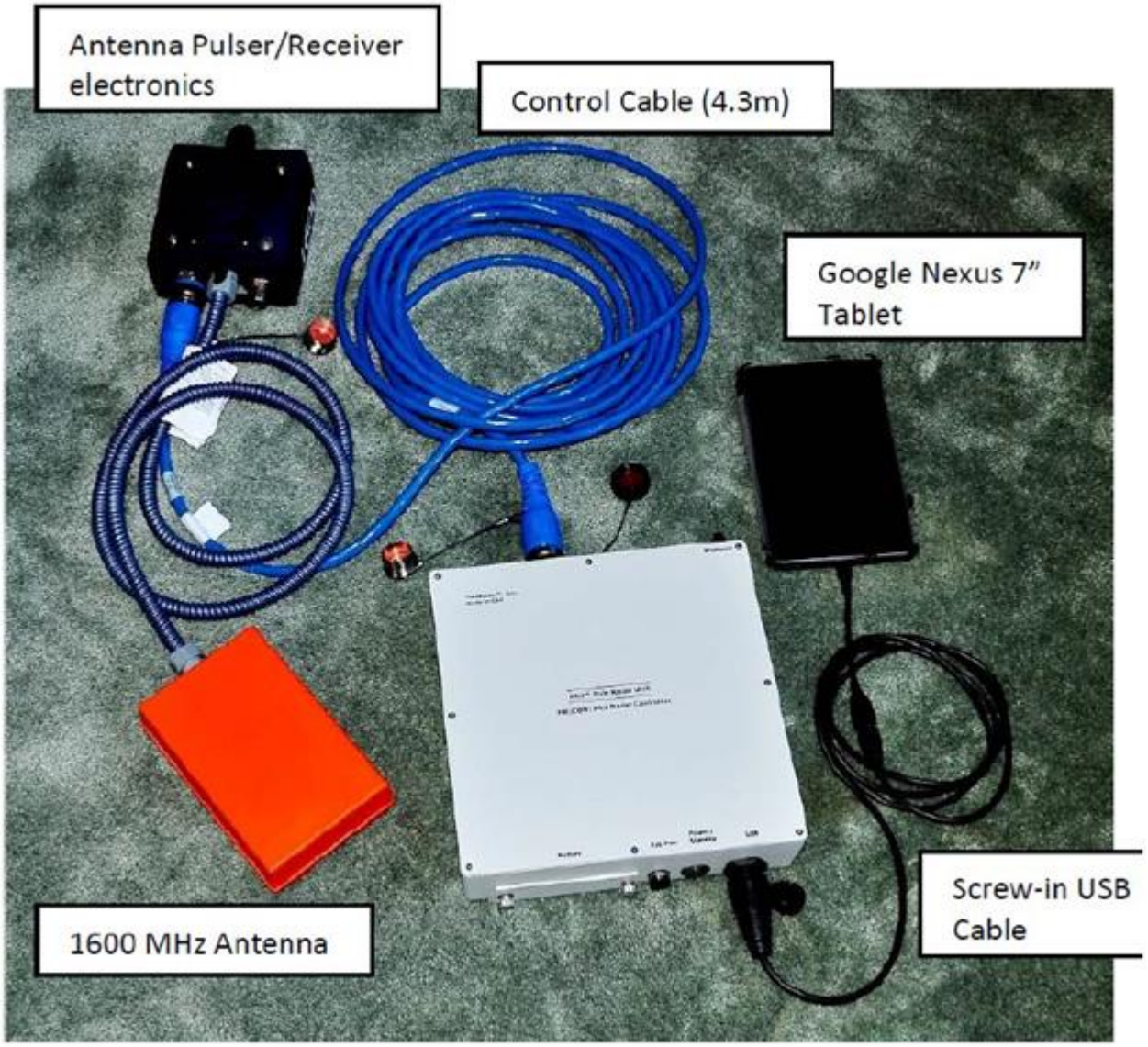
Pole inspection

- Local knowledge
- Visual inspection
- Hammer sound pole
- Above ground test
- Ground line test
- Below ground test
- Below ground decay
- Shell rot
- Excavate if required

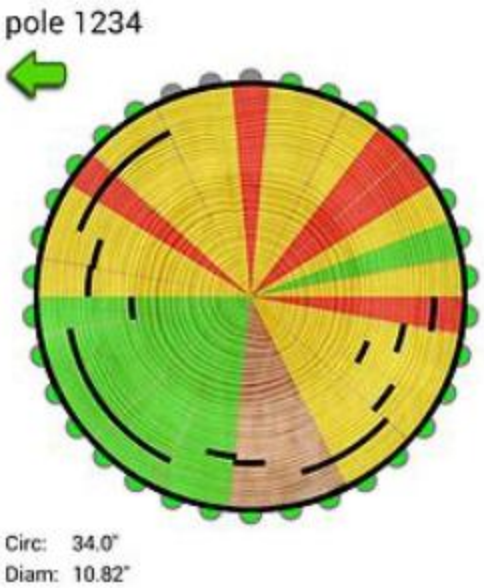
Pole Radar Unit (Ground Penetrating Radar)

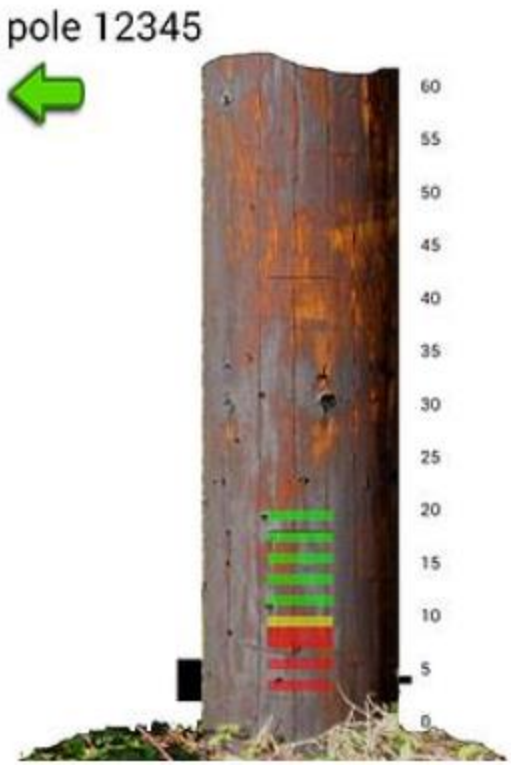
GPR Inspection employs electromagnetic waves which will reflect from a boundary between objects with different dielectric properties. The larger the difference between the dielectrics of two different materials, the larger the radar wave.

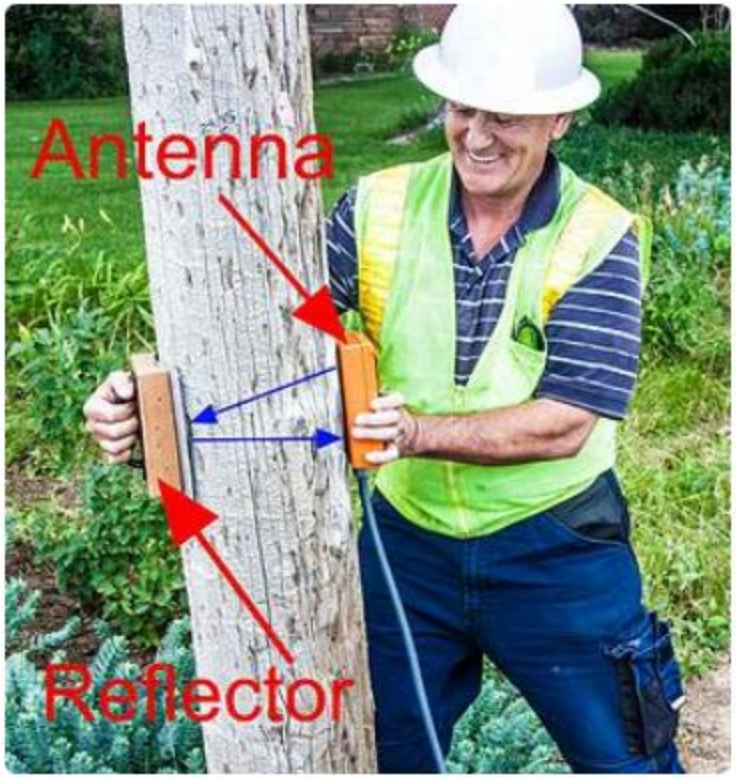
For example, the difference between the dielectric of good wood and compromised wood causes some of the radar energy to be reflected back to the surface antenna.



Vertical Scan





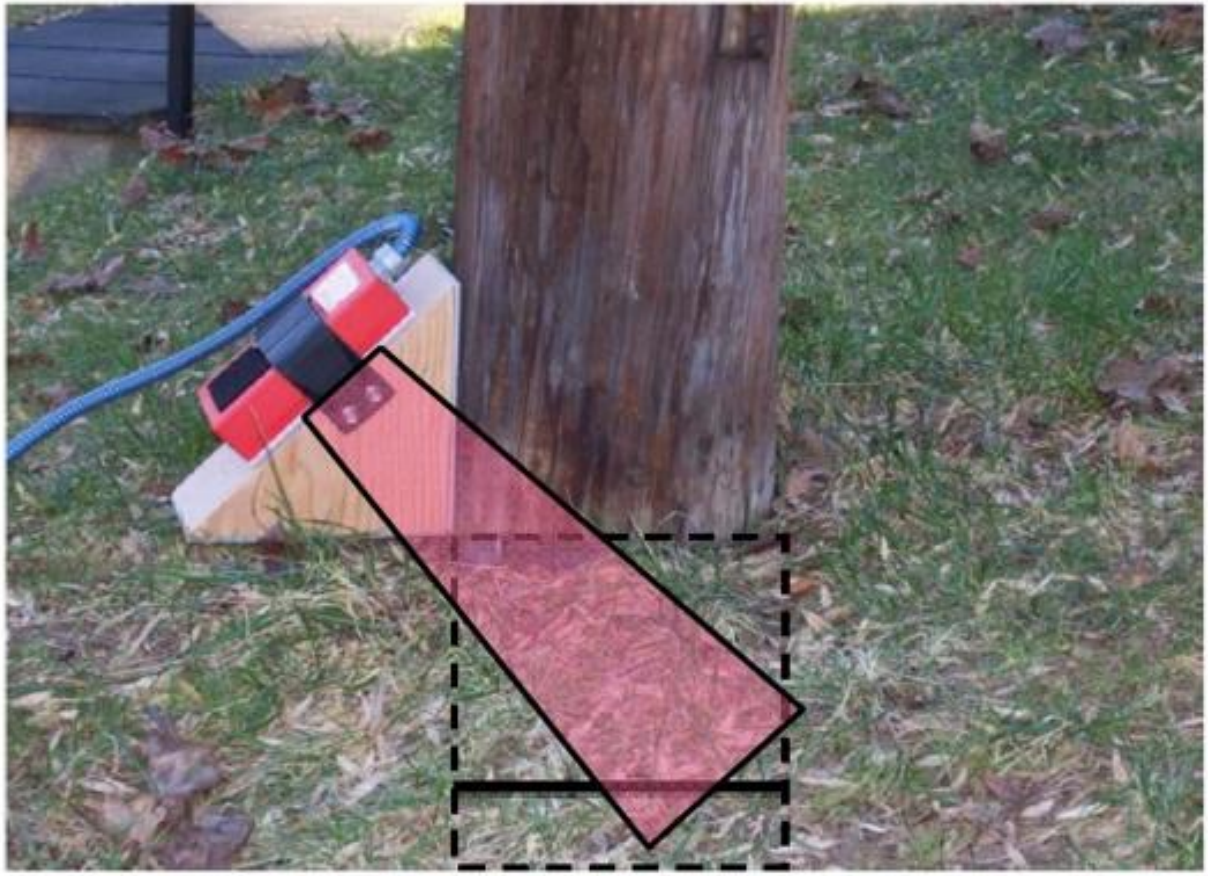


Click to enlarge

Non-Invasive Inspection of Wood Utility Poles for Detection and Mapping of Above- and Below-Ground Internal and External Decay

PRU 45deg Inspection Mode

Illustration of Radar Beam Orientation

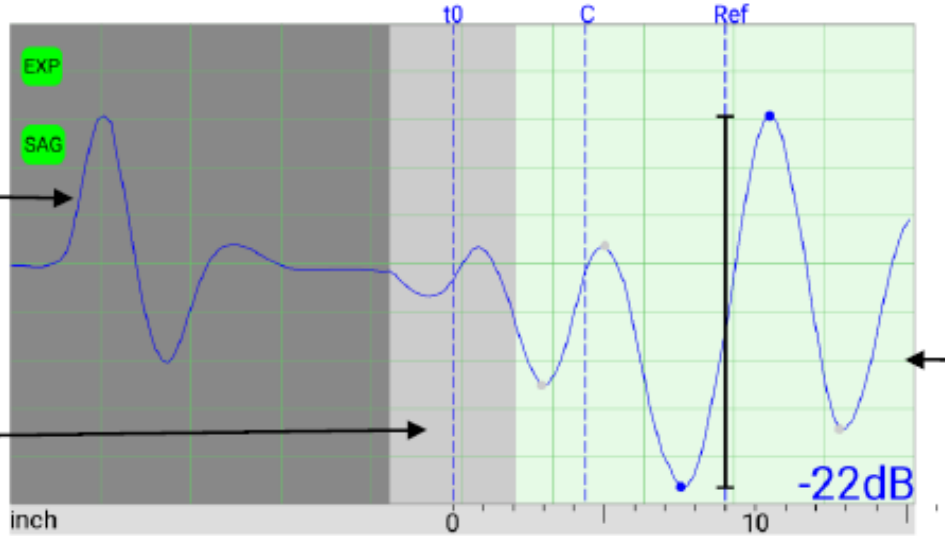


Non-invasive inspection of wood utility poles. Inspection below ground through concrete and asphalt.

PRU 45deg Inspection Mode

Entry Signal at Wedge/Pole interface Dark Gray Zone

Waveform ring down Light Gray Zone



t0=Pole entry
C = Pole Center
Ref=Pole Far Wall

REF = Reference Signal determined by Calibration Done for each Pole

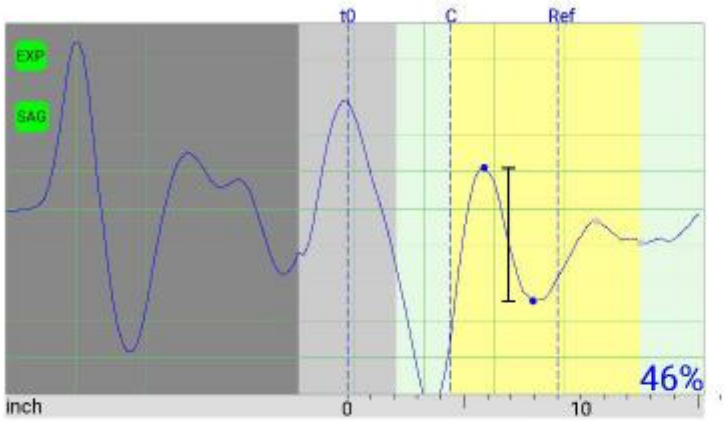
Pole: B2 45° diam: 9.0"

REF

FZ

Tap REF to show cross section

PRU 45deg Inspection Mode

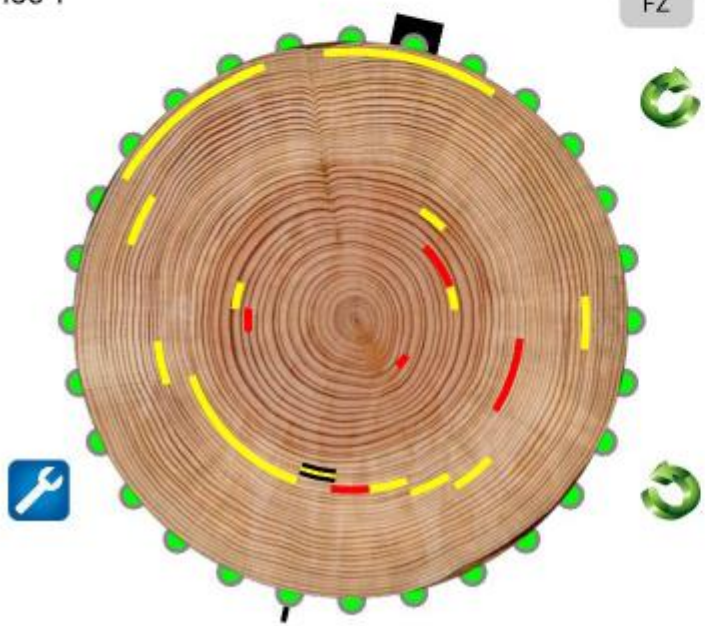


Pole: OTB2 45º diam: 9.0"

loc 1

ROT REF

FZ

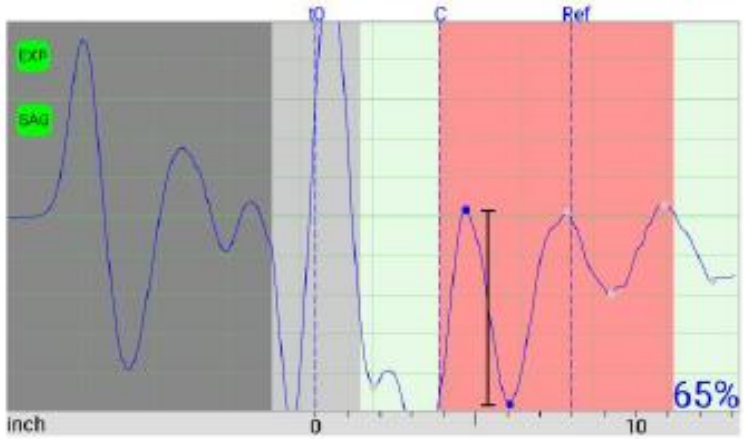


Pole B2 – Inspector Results

Deep decay starting 18" BG, located between 3 and 8 o'clock

Some early stage decay

PRU 45deg Inspection Mode

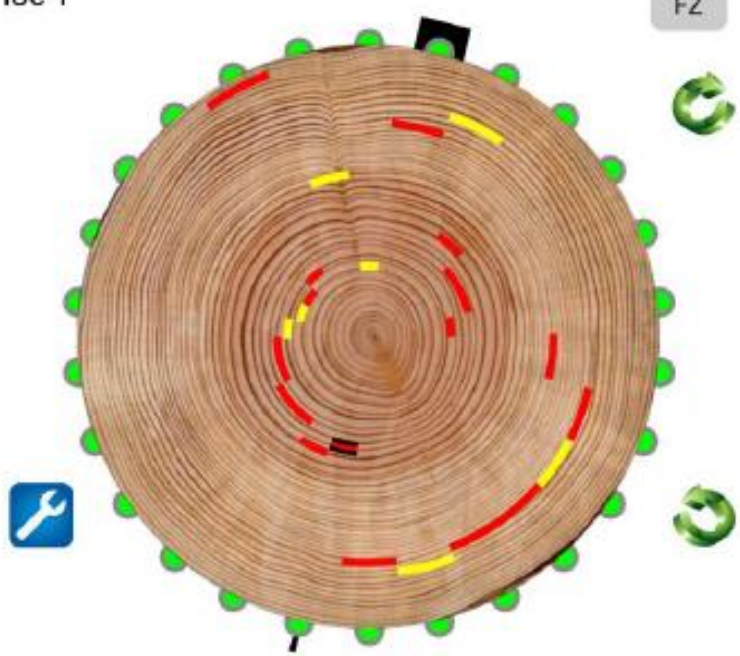


Pole: OTB6-1 45° diam: 8.5"

loc 1

ROT REF

FZ

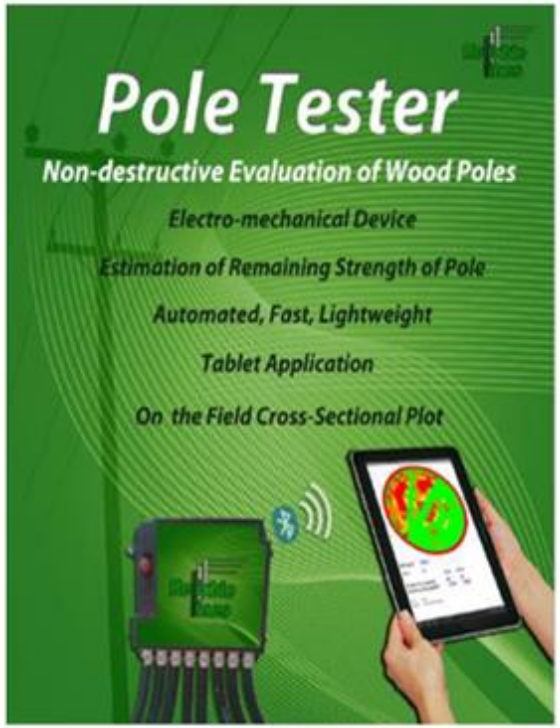


Pole B6 – Inspector Results

Shell Rot mainly between 4 and 6 o'clock

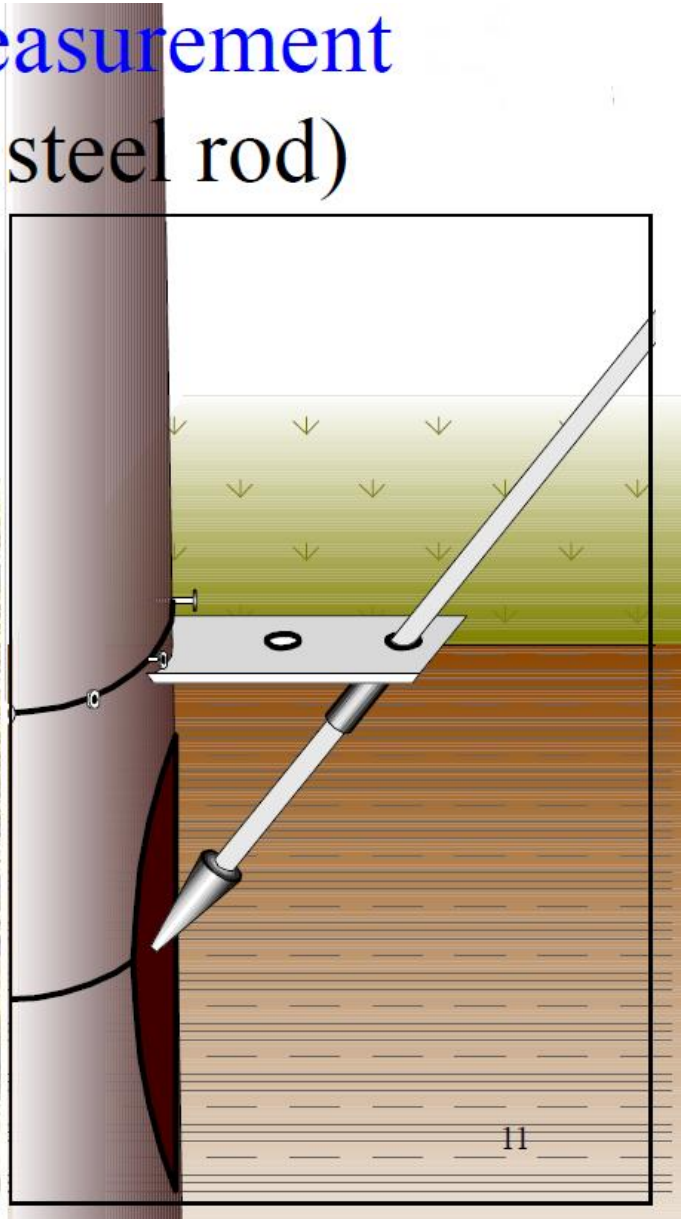
Some early stage decay

NDT – Pole Tester

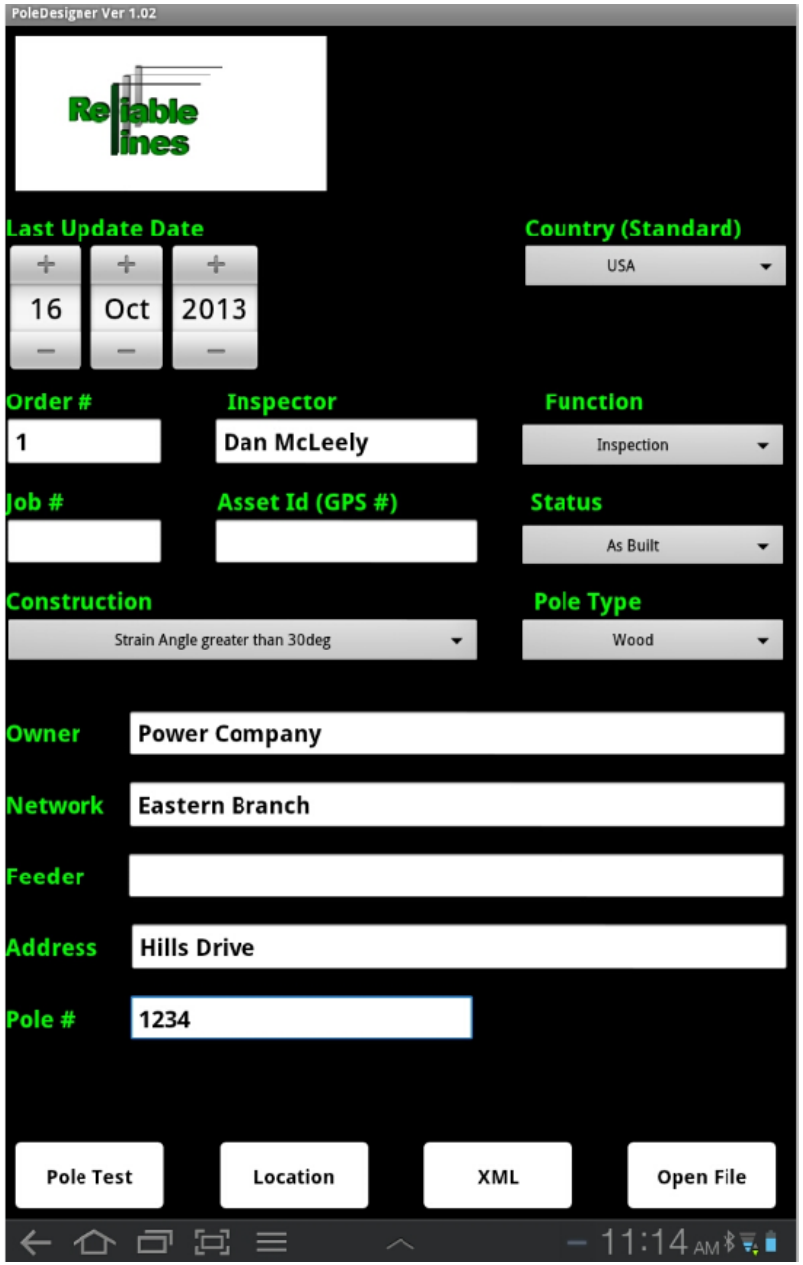


Shell rot below ground measurement

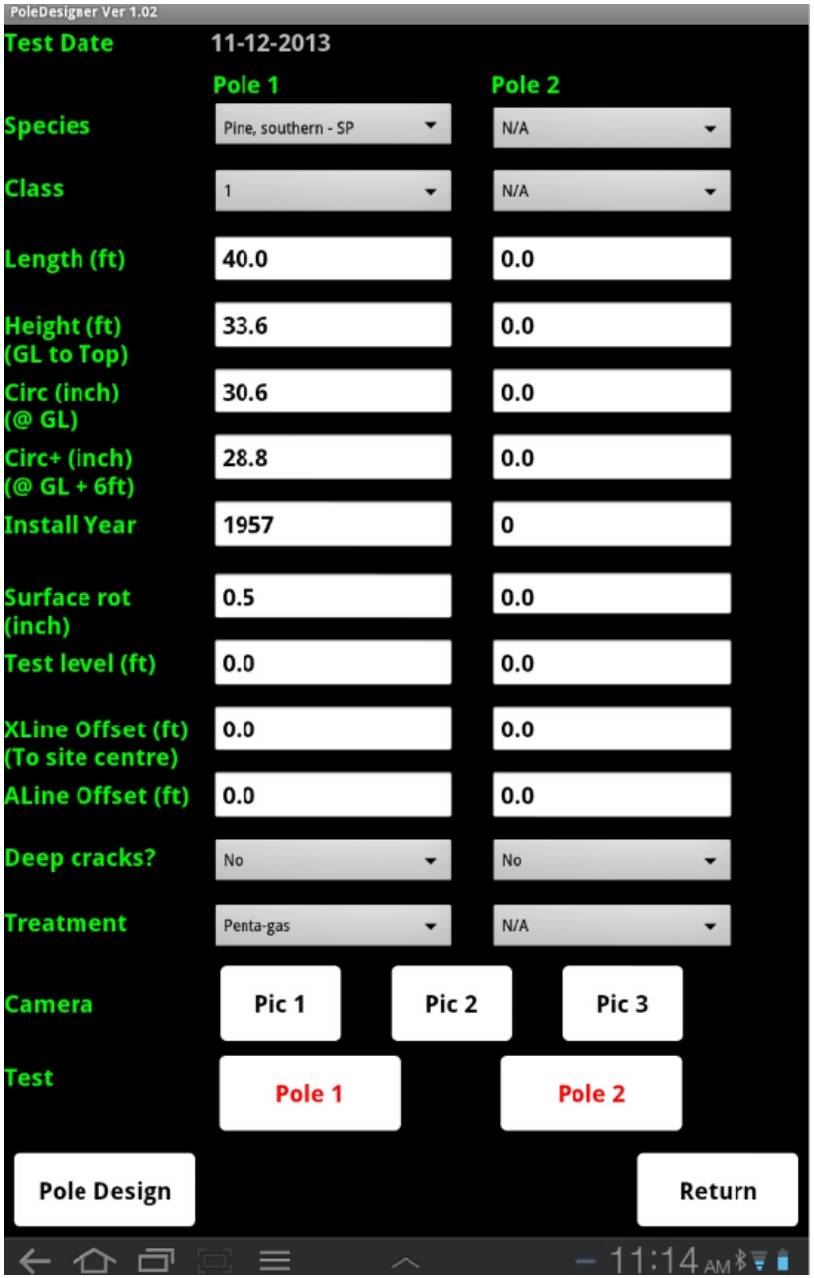
- Shell rot tool (stainless steel rod)
- 5mm, 10mm etc.



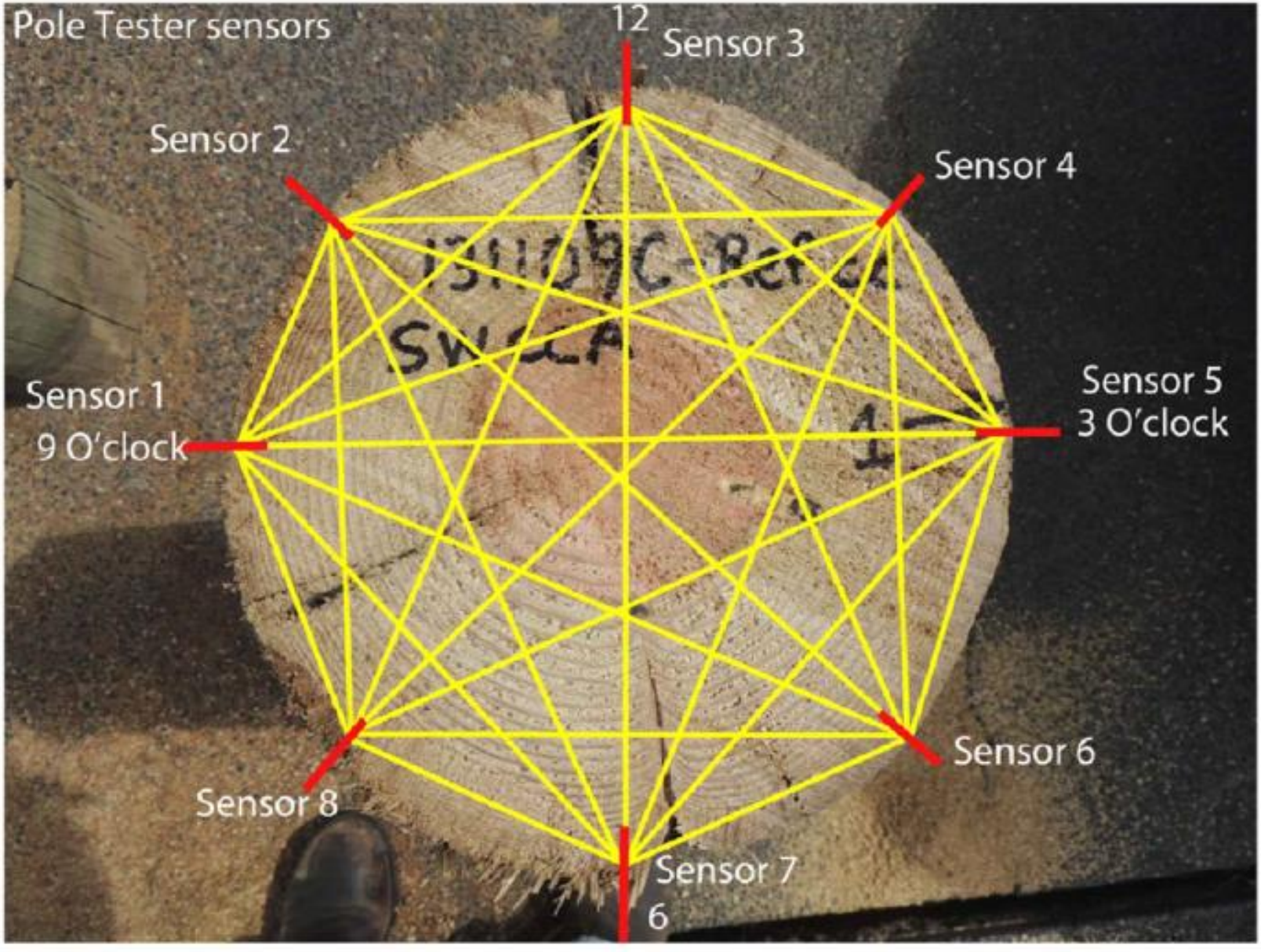
Pole Tester Software: Admin Screen



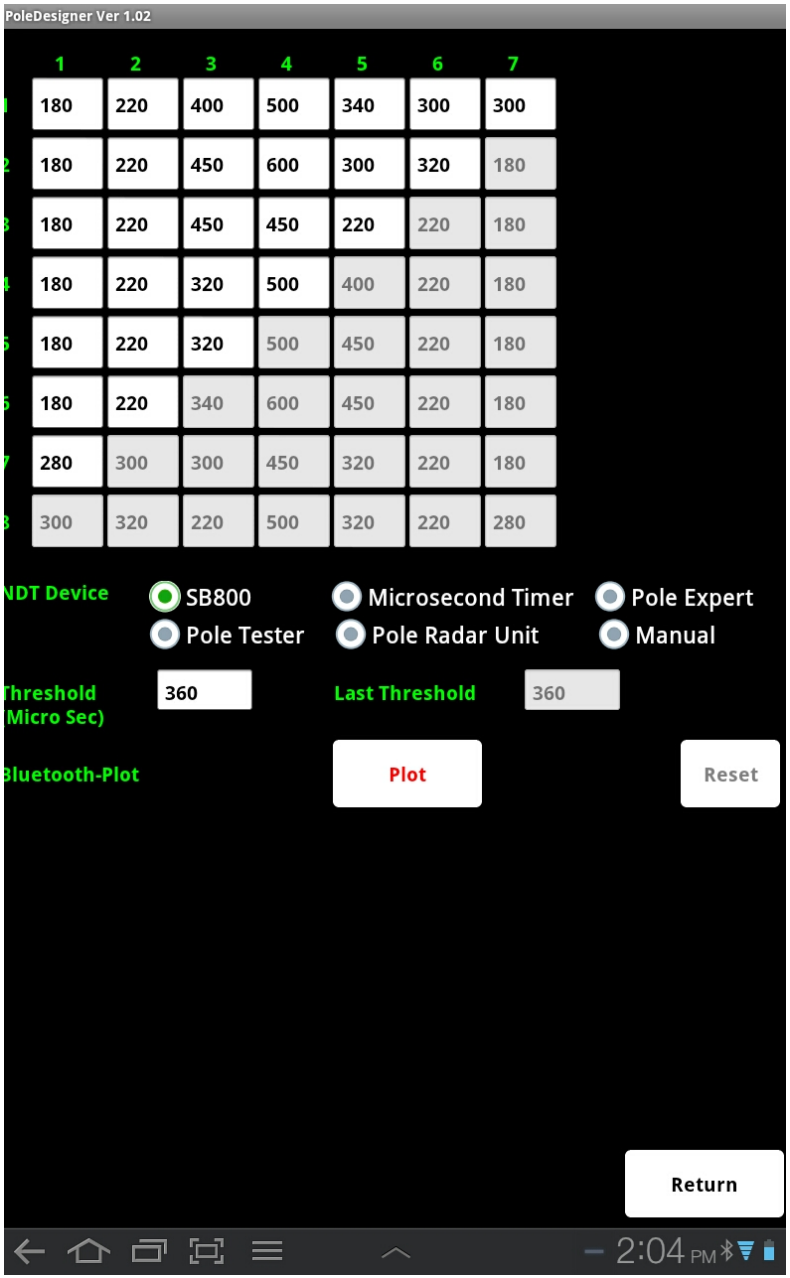
Pole Tester Software: Pole Data Capture Screen



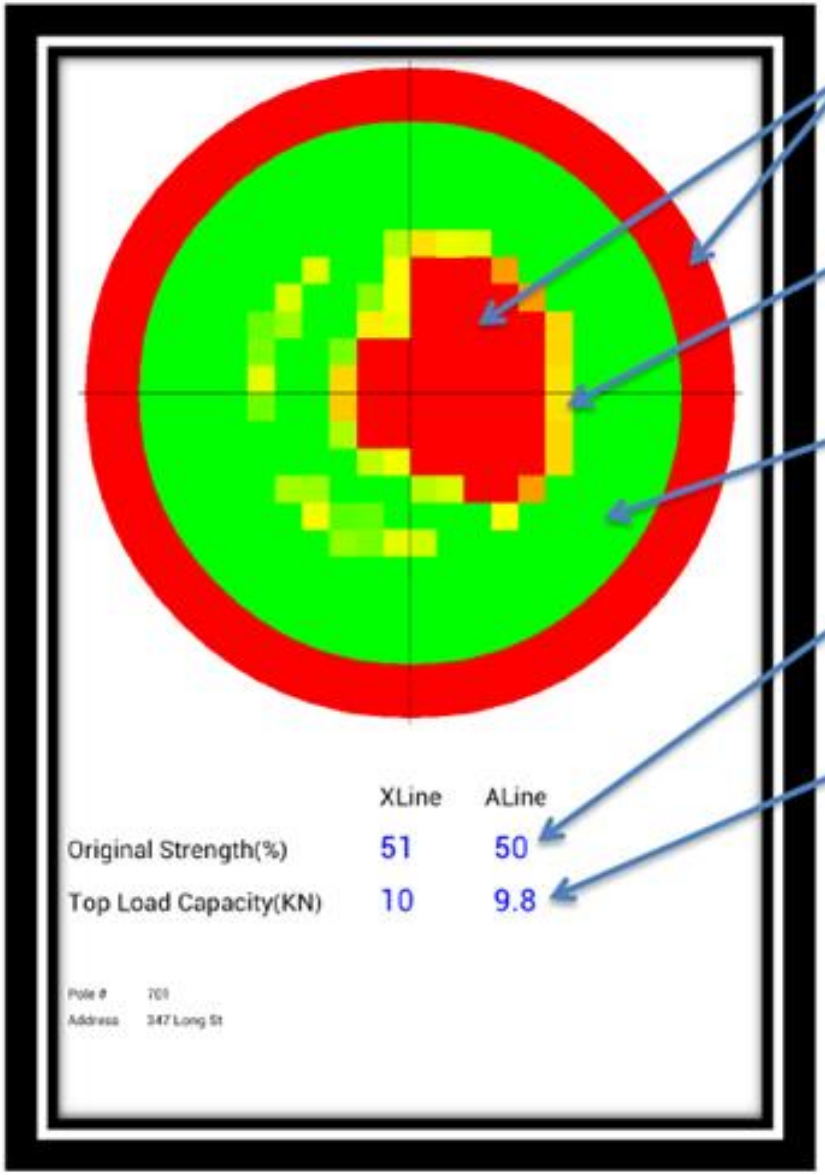
Pole Tester Sender-Receiver Signals



Pole Tester Software: Time of Flight Grid



Pole Tester Software Snapshot Report



Red = Decayed wood.

Yellow = Potentially decayed wood.

Green = Good wood.

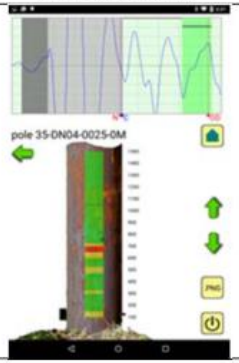
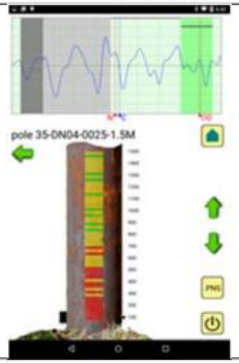
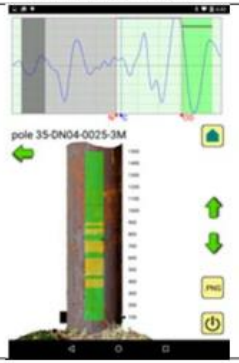
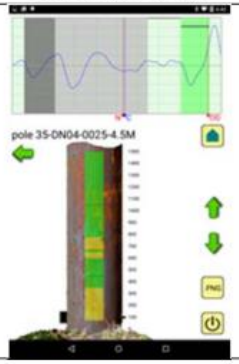
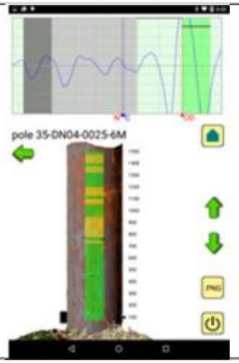
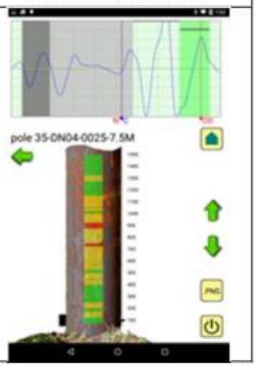
Original Strength %

Remaining Tip Load Capacity

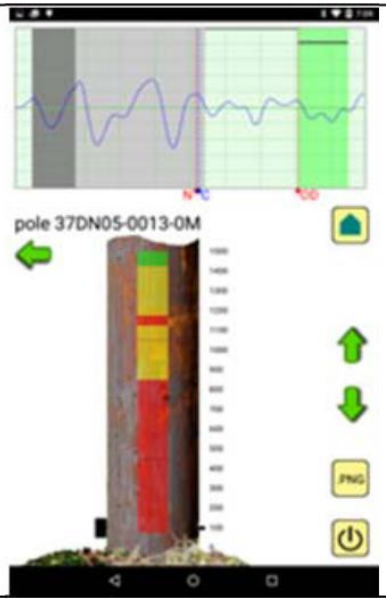
NDT Trial: ESB - Ireland

Pole Number	Duty Type	Brand Date	Species	Height	Drying Method	Manufacturer
DN-04-0025	*TP*	*2000*	*IP*	*11*	*A*	*Scan 1*

Location	0 m	1.5 m	3.0 m	4.5 m	6.0 m	7.5 m	9 m
Pole Tester	*98%/98%*	*42%/68%*	*48%/47%*	*39%/37%*	*58%/74%*	*94%/95%*	

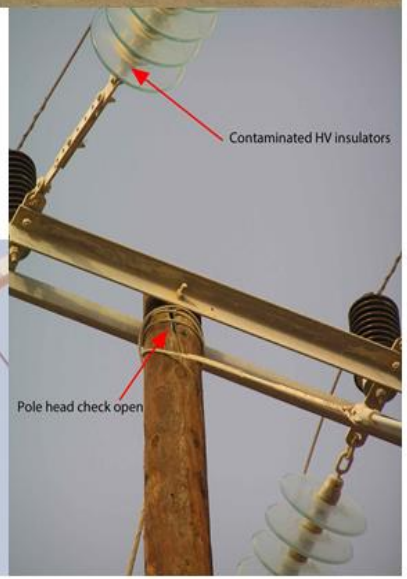
	0 m to 1.5 m	1.5 m to 3.0 m	3.0 m to 4.5 m	4.5 m to 6.0 m	6.0 m to 7.5 m	7.5 m to 9.0 m
Pole Radar Unit						

NDT Trial: ESB - Ireland

PoleTester	*56%/72%*	
	0 m to 1.5 m	
Pole Radar Unit		

Overhead Line Structure Design

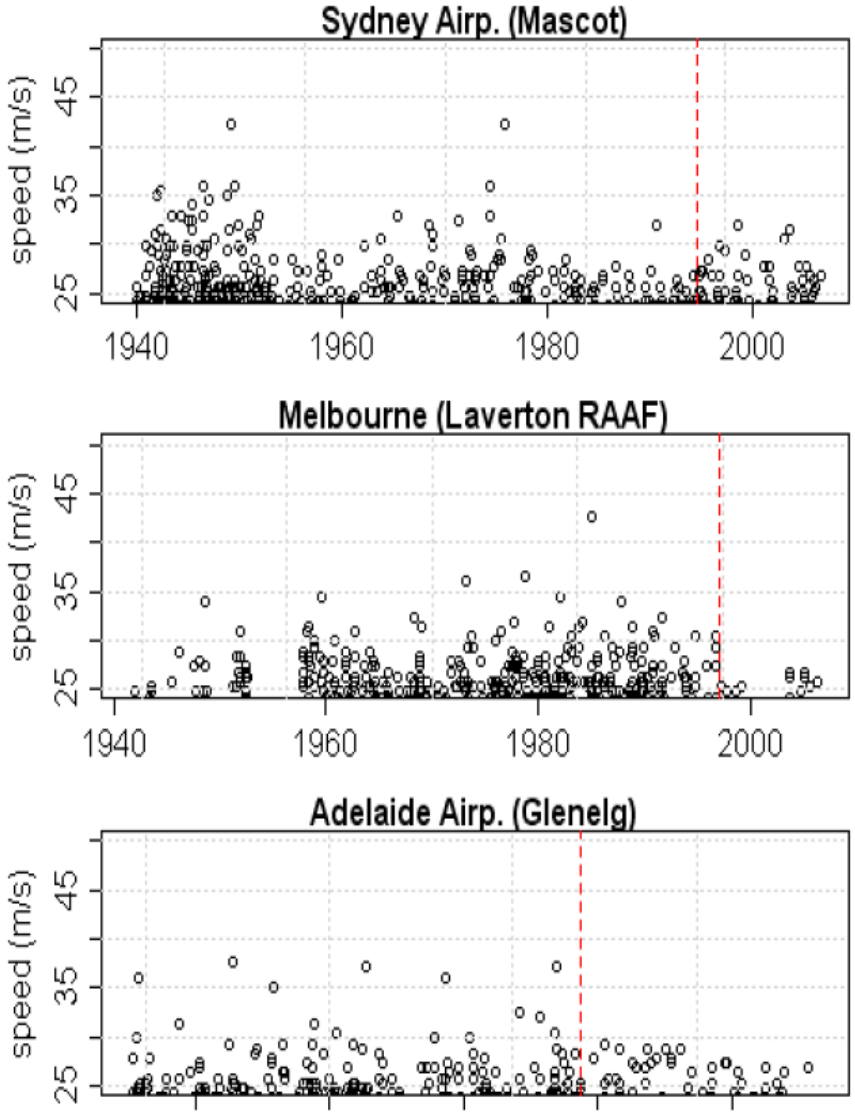
- Mobile Engineering Tablet Application
- Single or Double Structures
- Site and Environmental Factors
- Calculate Wind Loads
- Use Regional Historical Wind Data
- Measure Conductor Spans and Sags
- Stay Wires
- Transformers
- Attachments
- Produce Structure Health Indicators
  - Probability of Failure
  - Reliability Index
  - Condition Category
  - Time To Failure



Pole Designer software – Reliability

- Structure Health Indicators
- POF: Probability Of Failure
- RI: Reliability Index
- CC: Condition Category
- TTF: Time To Failure

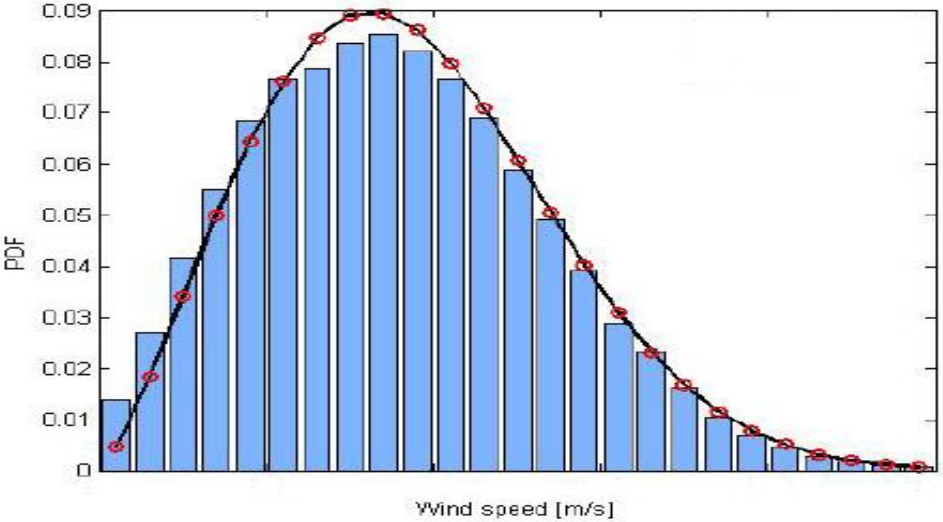
Historical Extreme Wind



Time-series plots of the daily maximum gust wind speed (above a threshold of 25 m/s) for the Sydney, Melbourne and Adelaide (airport) meteorological observing stations

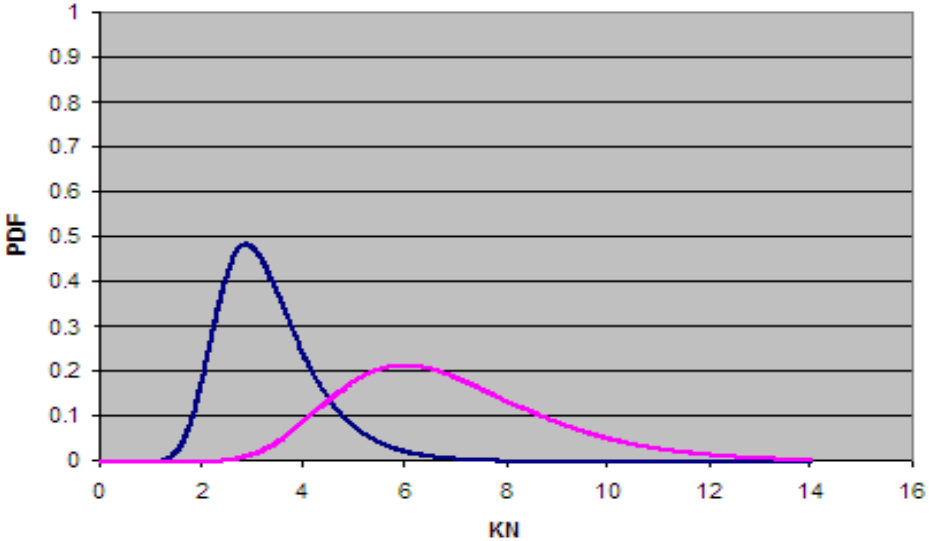
Variability of load and strength

-Probabilistic approach takes into account uncertainties in measuring pole strength and wind load.



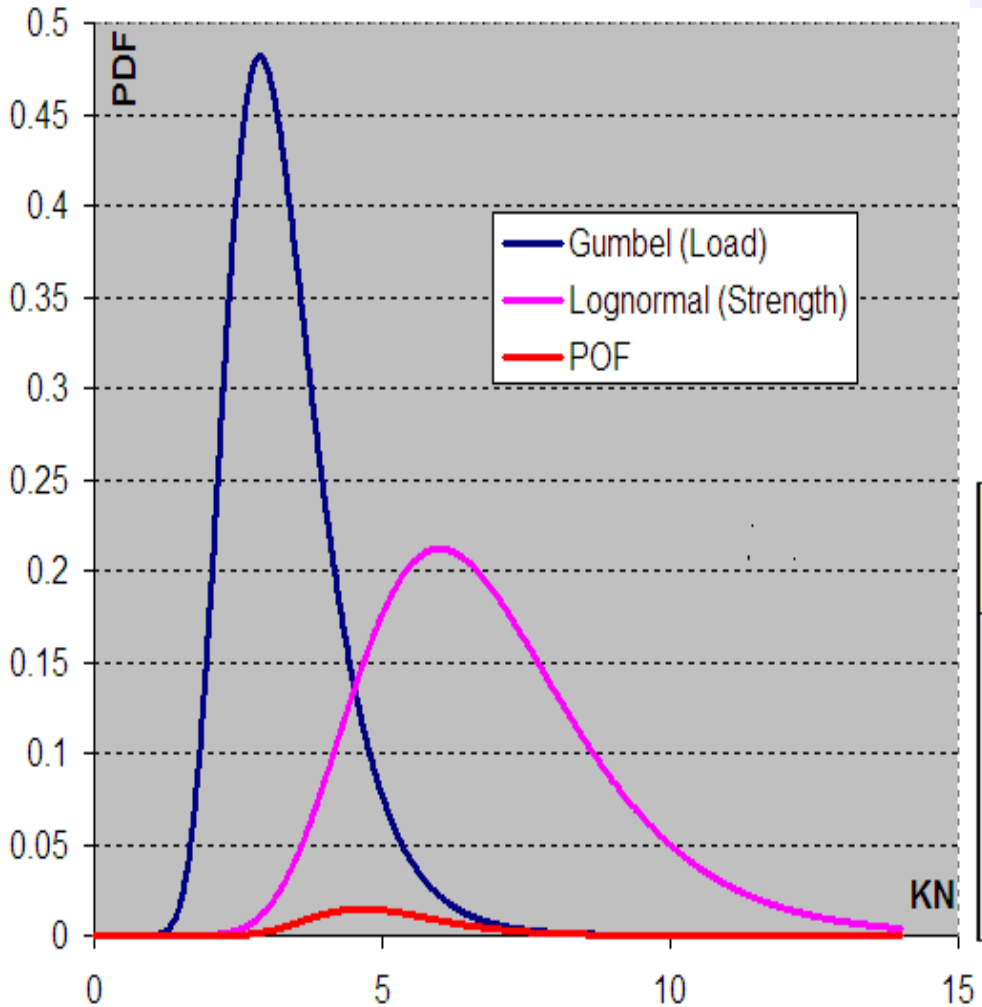
-Gumbel distribution is used to model extreme annual wind load.

-Lognormal distribution is used to model uncertainties in pole strength.



Probability of Failure (Reliability Index)

$$P_F = P(R \le Q) = \int_{-\infty}^{+\infty} P(x \le R \le x + dx) P(Q \ge x) dx$$



Gumbel Distribution

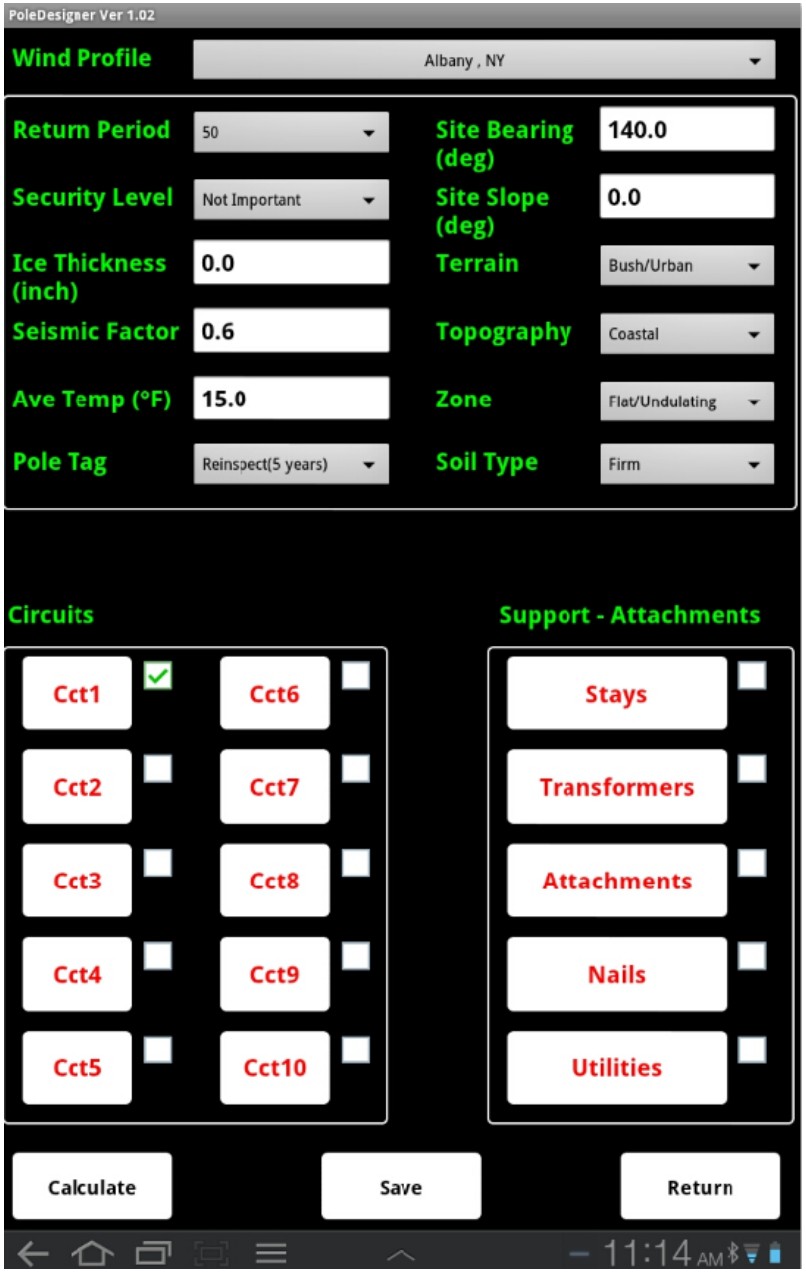
$$f(x) = \frac{1}{\beta} e^{-\frac{x-\mu}{\beta}} e^{-e^{-\frac{x-\mu}{\beta}}}$$

Lognormal Distribution

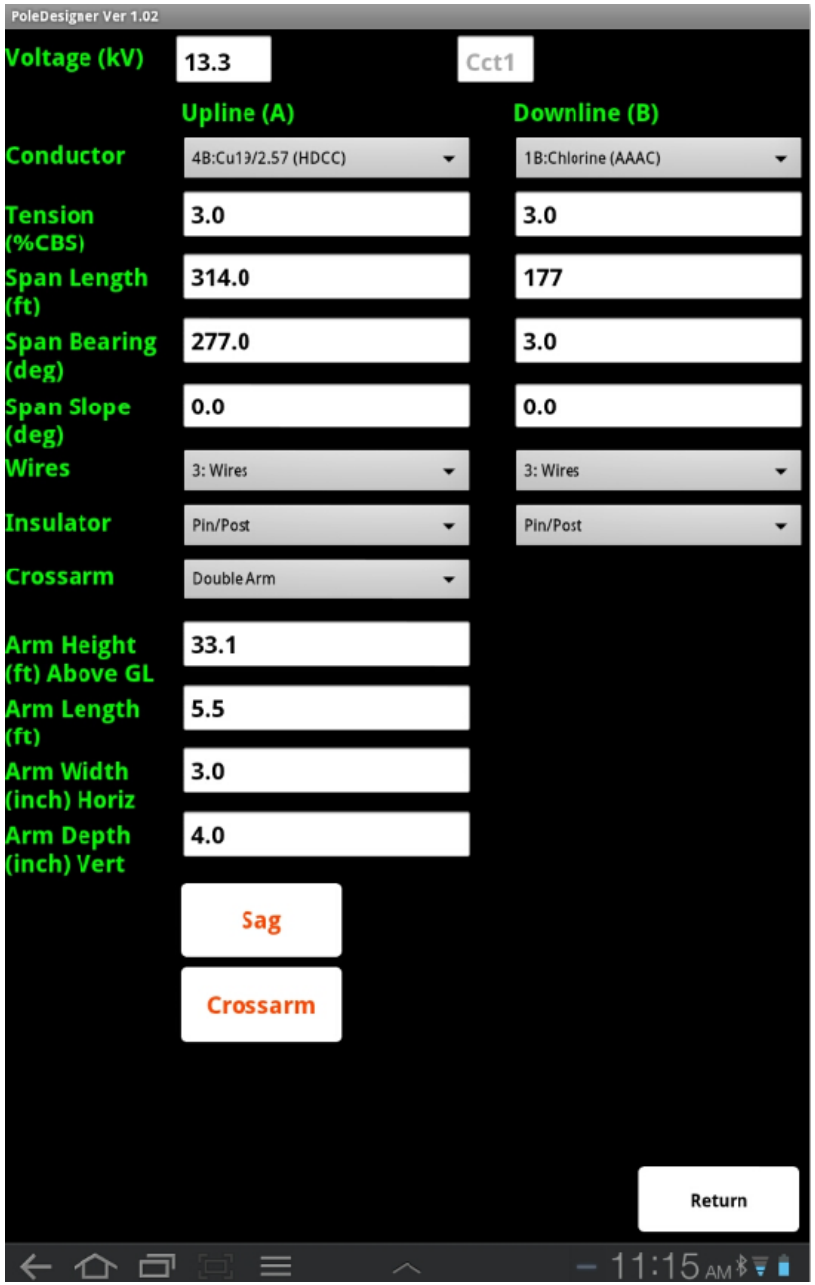
$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln(x)-\mu)^2}{2\sigma^2}}$$

Reliability Index β	Probability of failure $P_f = 1 - \phi(\beta)$	Expected Performance Level
β <= 1.0	POF >= 0.16	Hazardous
1.0 < β <= 2.0	0.16 > POF > 0.023	Poor
2.0 < β <= 3.0	0.023 > POF >= 0.001	Average
3.0 < β <= 5.0	0.001> POF >= 0.0000003	Good
β > 5.0	POF < 0.0000003	High

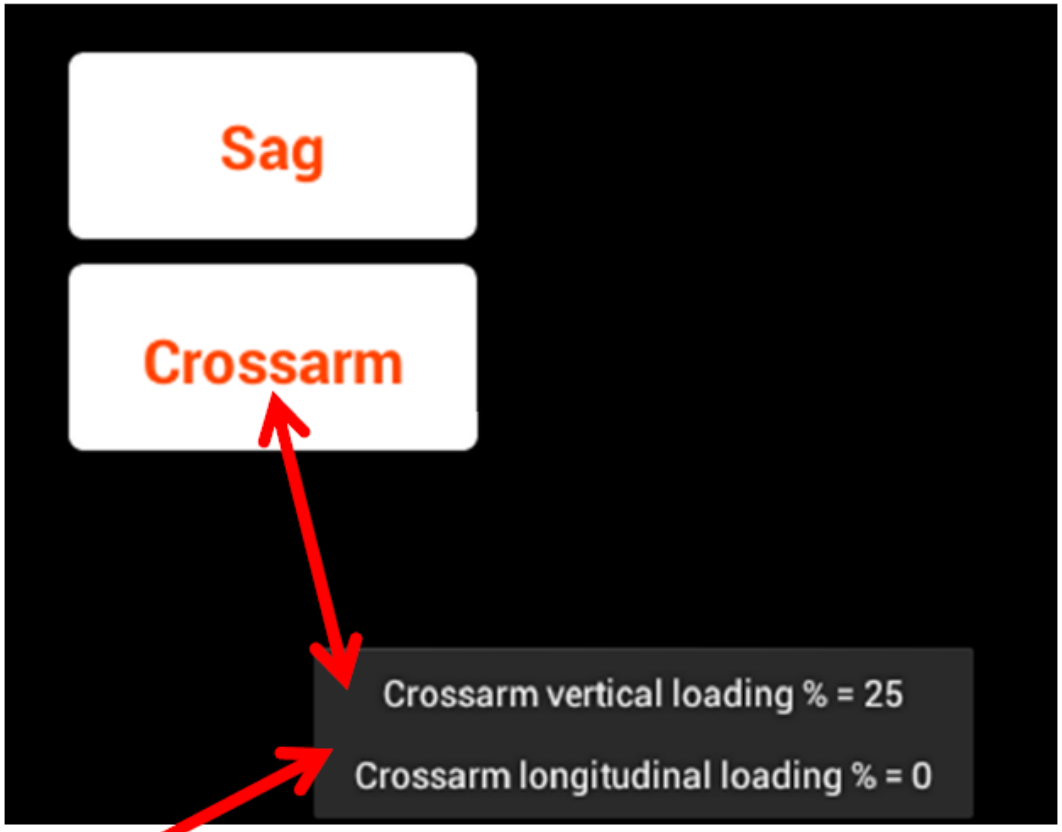
Pole Designer Software: Data Capture Dashboard



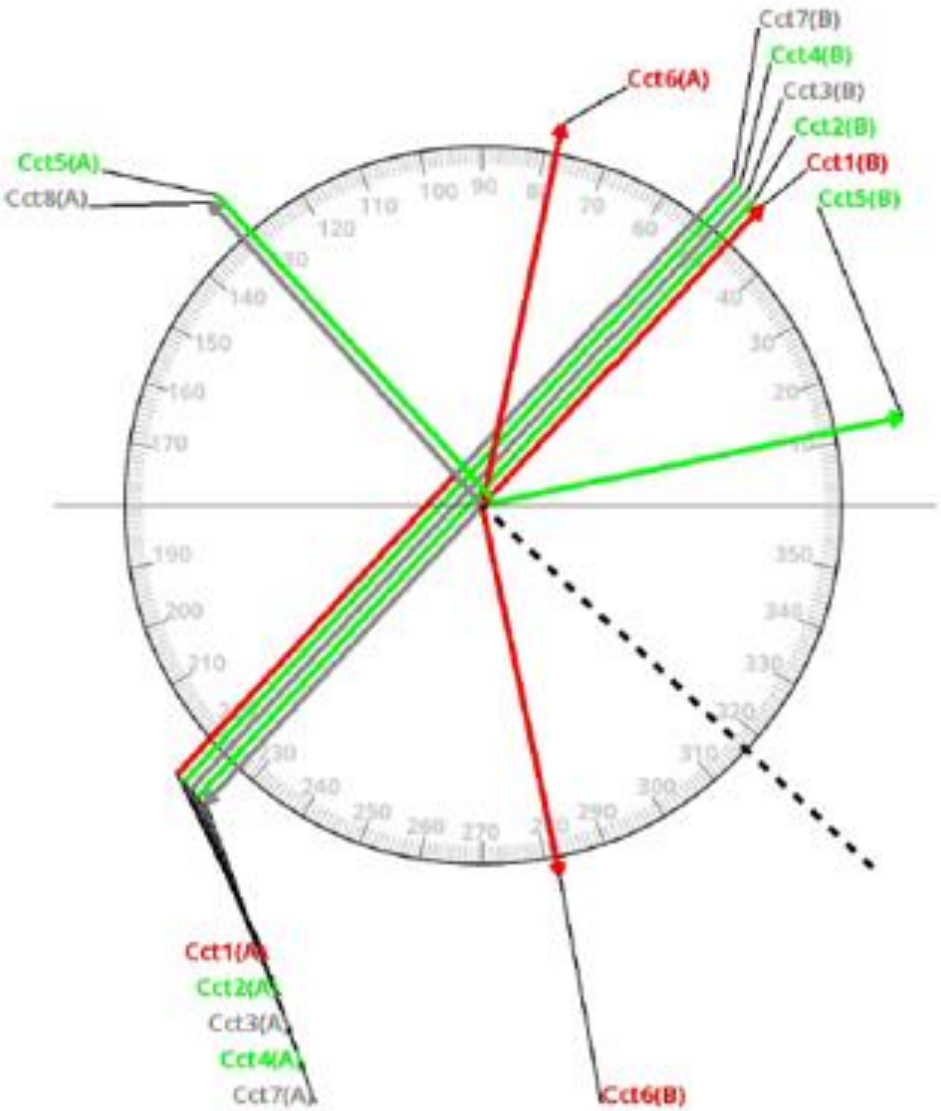
Pole Designer Software: Conductor Data Capture



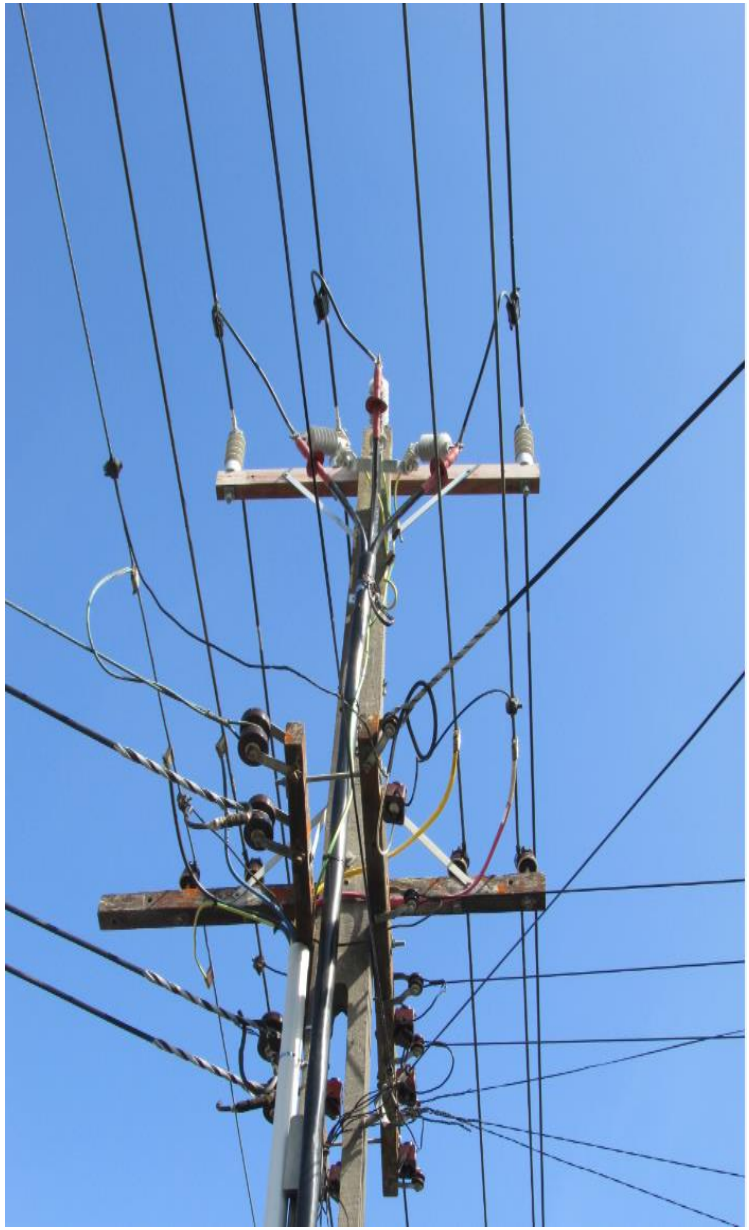
Pole Designer – crossarm loads

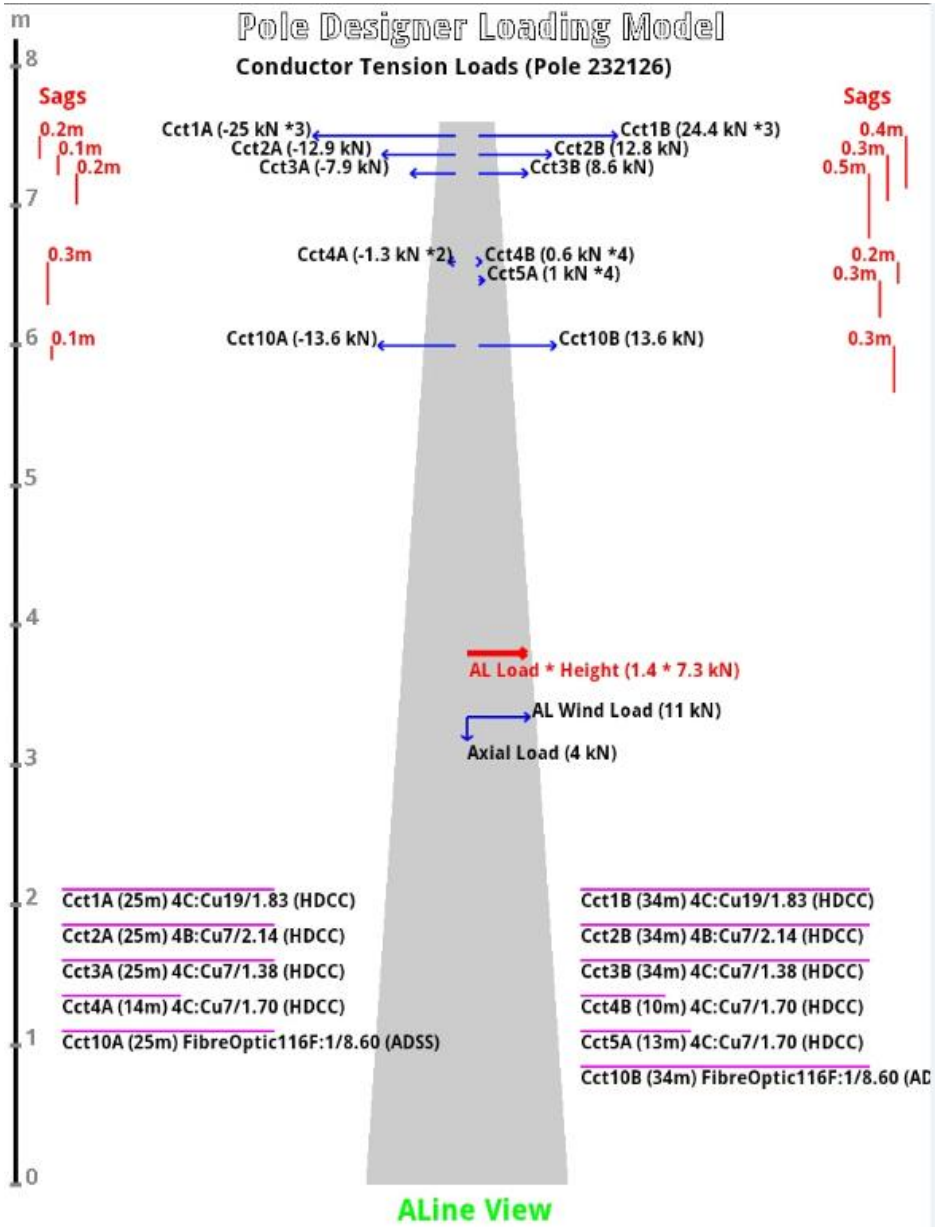


Pole Designer Compass: Conductor Bearings

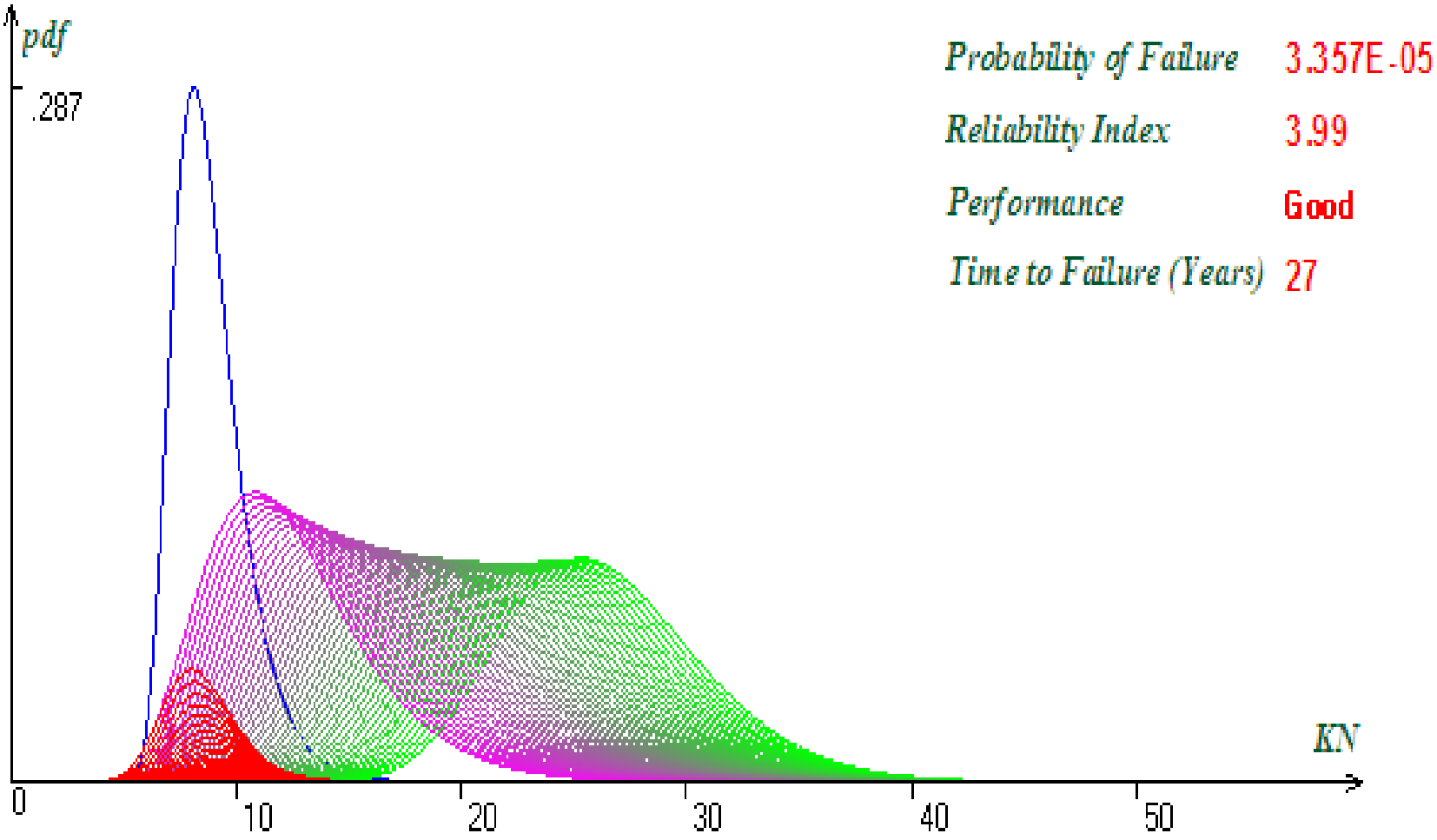


Pole Designer Loading Model

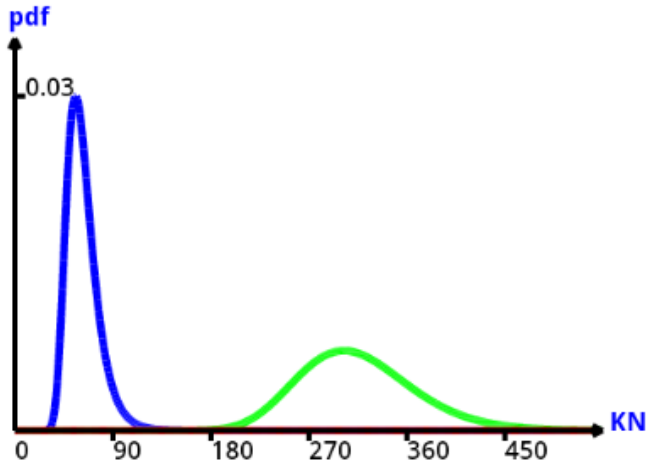




Time to Failure



Pole Designer Report: High Reliability Structure



Graphs: Blue - Wind Load Green - Pole Strength Red - Probability of Failure

POF : 0
RI : 6.14
TTF (Years) : 22
Condition : High

Design Wind : 924 Pa
XL Load : 11.1 kN
AL Load : 2.4 kN
Axial Load : 10.4 kN

	XLine	ALine
%Strength	100	100
TopLoad(kN)	39.3	39.3

Pole # : 1AH10mHigh
Test Date : 25/9/2012
Owner : Reliable Lines Ltd
Network : New Zealand
Feeder : 3 Bridges
Address : 64 Dancansby Rd

PoleTag: Reinspect(10 years)

Structure : Wood, Important, Inspection, As Built, Construction: Pin no angle
Pole : Group (S3), Height (10.0 m), Diam @GL (380 mm), Diam @GL+2m (360 mm)

Circuit 1A : 33.0 KV , 1B:Cockroach (AAC) , CBS 10% , Span 70 m , N/A , N/A Insulator
Circuit 1B : 33.0 KV , 1B:Cockroach (AAC) , CBS 10% , Span 70 m , N/A
Crossarm : Single Arm , Height 9.9 m , Length 2.4 m , Width 100 mm , Depth 100 mm

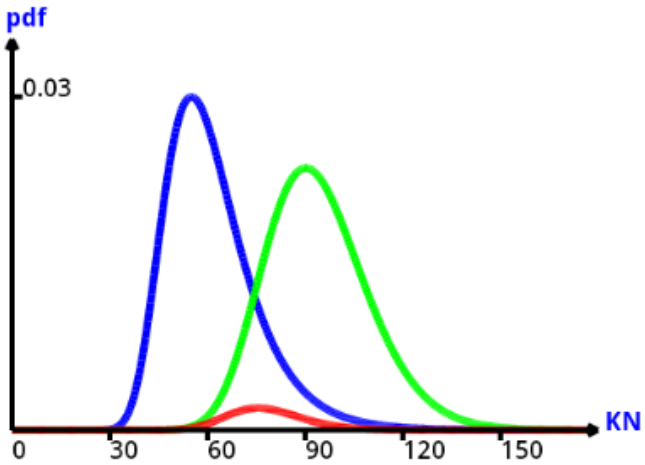
Circuit 2A : 11.0 KV , 1B:Cricket (AAC) , CBS 10% , Span 70 m , 3 Wires , N/A Insulator
Circuit 2B : 11.0 KV , 1B:Cricket (AAC) , CBS 10% , Span 70 m , 3 Wires
Crossarm : Single Arm , Height 8.4 m , Length 2.1 m , Width 75 mm , Depth 100 mm

Circuit 3A : 0.4 KV , 1C:Rango (AAC) , CBS 14% , Span 70 m , 4 Wires , N/A Insulator
Circuit 3B : 0.4 KV , 1C:Rango (AAC) , CBS 14% , Span 70 m , 4 Wires
Crossarm : Single Arm , Height 7.2 m , Length 1.8 m , Width 100 mm , Depth 75 mm

Circuit 4A : 0.4 KV , 1C:Kutu (AAC) , CBS 5% , Span 30 m , 4 Wires , Strain Insulator
Crossarm : Single Arm , Height 6.6 m , Length 1.8 m , Width 100 mm , Depth 75 mm

Circuit 5A : 0.4 KV , 1C:Rango (AAC) , CBS 8% , Span 45 m , 4 Wires , N/A Insulator
Crossarm : Single Arm , Height 6.6 m , Length 1.8 m , Width 100 mm , Depth 75 mm

Pole Designer Report: Low Reliability Structure



Graphs: Blue - Wind Load Green - Pole Strength Red - Probability of Failure

POF :	0.062197904
RI :	1.54
TTF (Years) :	2.8
Condition :	Poor

Design Wind :	924 Pa
XL Load :	11 kN
AL Load :	2.2 kN
Axial Load :	8 kN

		XLine	ALine
%Strength	:	44	54
TopLoad(kN)	:	10.5	12.7

Pole # :	4AH10mPoor
Test Date :	25/9/2012
Owner :	Reliable Lines Ltd
Network :	New Zealand
Feeder :	3 Bridges
Address :	64 Dancansby Rd

PoleTag:	Yellow Tag

Structure :	Wood, Important, Inspection, As Built, Construction: Pin no angle
Pole :	Group (S3), Height (10.0 m), Diam @GL (320 mm), Diam @GL+2m (300 mm), Rot (15 mm)
Circuit 1A :	33.0 KV , 1B:Cockroach (AAC) , CBS 10% , Span 70 m , N/A , N/A Insulator
Circuit 1B :	33.0 KV , 1B:Cockroach (AAC) , CBS 10% , Span 70 m , N/A
Crossarm :	Single Arm , Height 9.9 m , Length 2.4 m , Width 100 mm , Depth 100 mm
Circuit 2A :	11.0 KV , 1B:Cricket (AAC) , CBS 10% , Span 70 m , 3 Wires , N/A Insulator
Circuit 2B :	11.0 KV , 1B:Cricket (AAC) , CBS 10% , Span 70 m , 3 Wires
Crossarm :	Single Arm , Height 8.4 m , Length 2.1 m , Width 75 mm , Depth 100 mm
Circuit 3A :	0.4 KV , 1C:Rango (AAC) , CBS 14% , Span 70 m , 4 Wires , N/A Insulator
Circuit 3B :	0.4 KV , 1C:Rango (AAC) , CBS 14% , Span 70 m , 4 Wires
Crossarm :	Single Arm , Height 7.2 m , Length 1.8 m , Width 100 mm , Depth 75 mm
Circuit 4A :	0.4 KV , 1C:Kutu (AAC) , CBS 5% , Span 30 m , 4 Wires , Strain Insulator
Crossarm :	Single Arm , Height 6.6 m , Length 1.8 m , Width 100 mm , Depth 75 mm
Circuit 5A :	0.4 KV , 1C:Rango (AAC) , CBS 8% , Span 45 m , 4 Wires , N/A Insulator
Crossarm :	Single Arm , Height 6.6 m , Length 1.8 m , Width 100 mm , Depth 75 mm

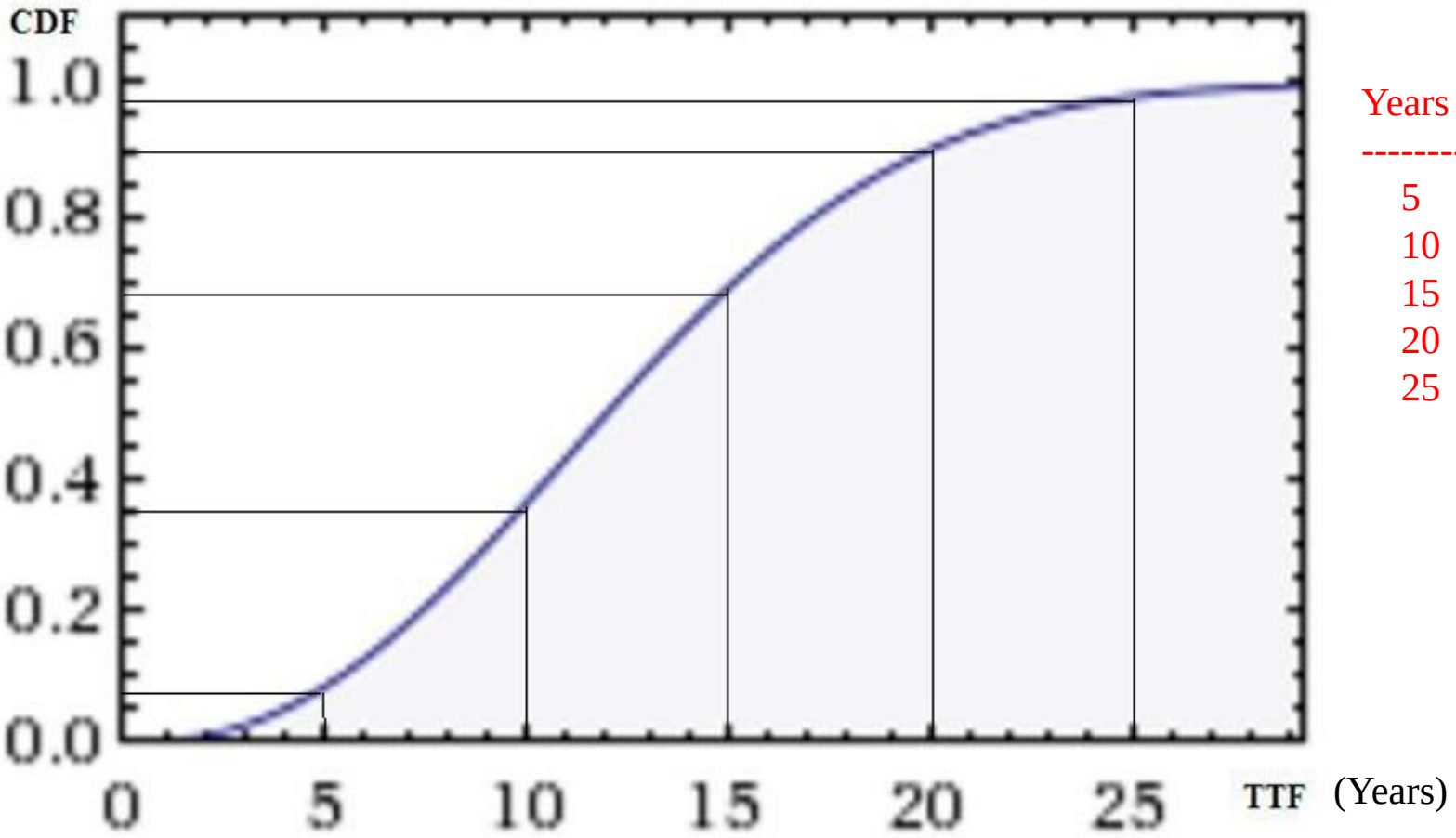
Modelling Time to Failure Data

Hazard or Survivability Function built from Time to Failure data for a network of poles demonstrates:

- Reliability of the network
- Scope of the future pole replacements
- A means for valuation analysis

Planning pole replacements

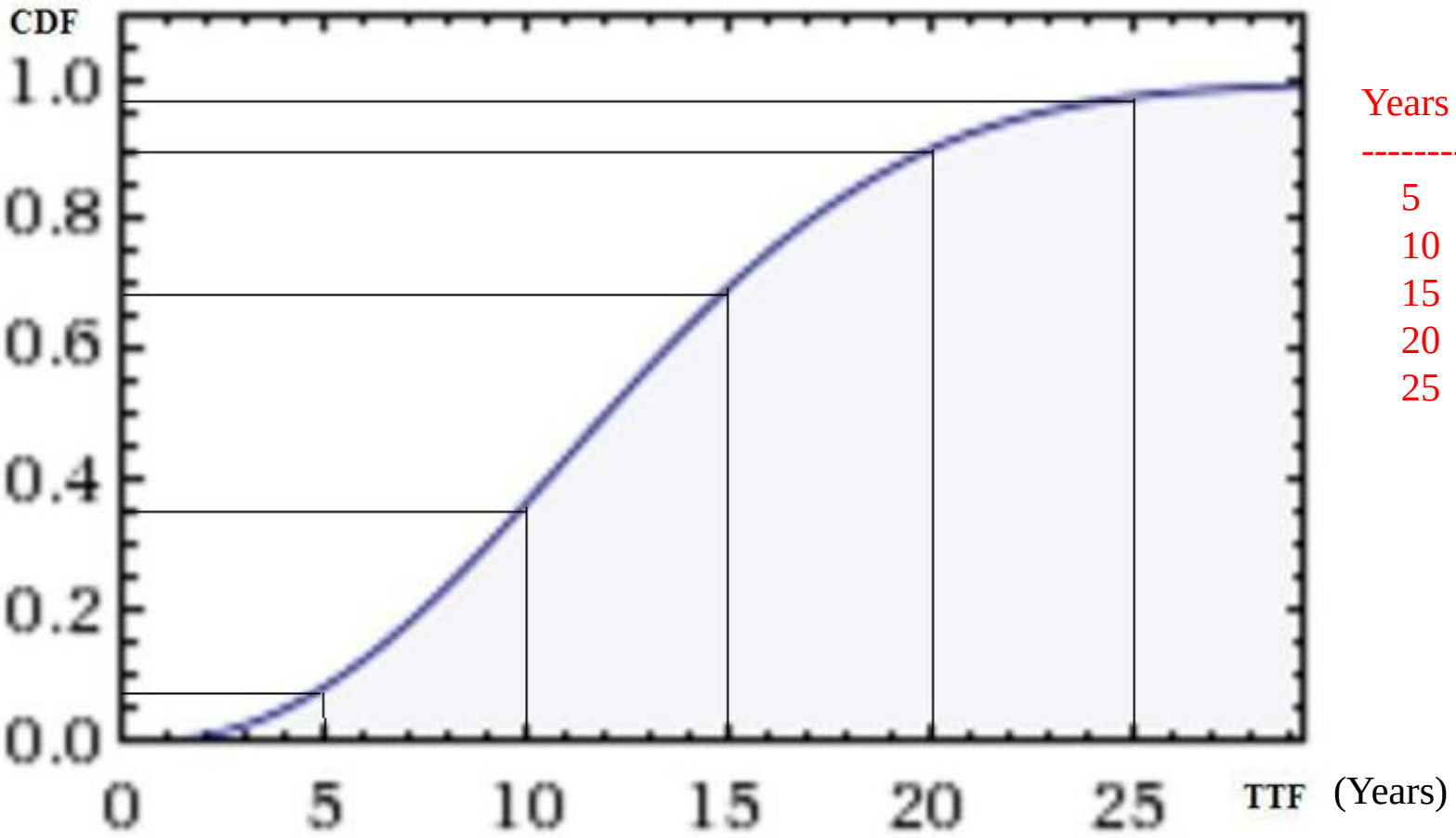
Weibull Cumulative Distribution Function of Time To Failure Data



Years	%Replace
5	7
10	35
15	68
20	90
25	97

Planning pole replacements

Weibull Cumulative Distribution Function of Time To Failure Data



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