Use of Artificial Intelligence for Analysing Structural Health Monitoring Data from Concrete Structures

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Outline of Presentation

- Background
- Role of Artificial Intelligence in SHM
- Research objectives
- Experimental details
- Initial Observations from the data
- Application of AI to SHM data
- Results and discussion
- Conclusions and recommendations for future work

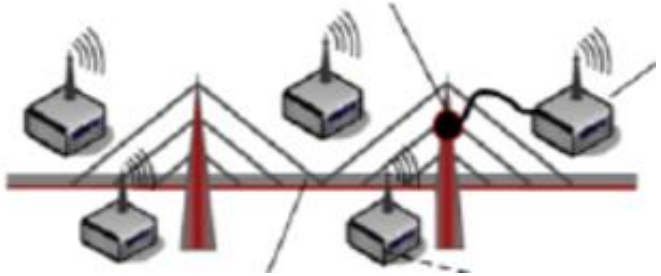
“If you can predict it, you can prevent it”

Structural Health Monitoring

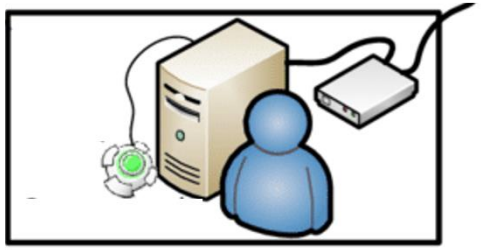
An innovative technology to automatically sense, provide and evaluate timely information about the condition and performance of structures at both global and local levels.

Electrical Resistivity sensors
Temperature sensors

Wireless sensor nodes

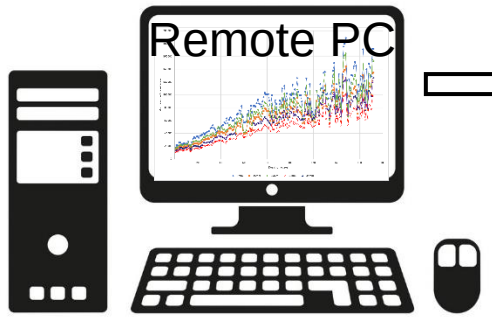


Monitored Structure

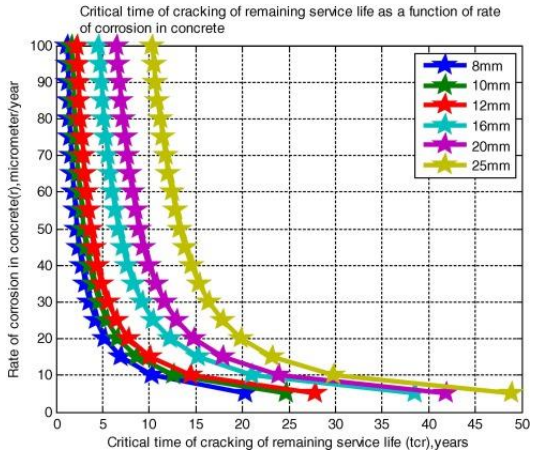


Base Station

Cloud computing



Collection of raw data



Service Life Modelling

Plan of Action & Maintenance Procedure

Increased Serviceability

Improved Safety

Real-time Maintenance

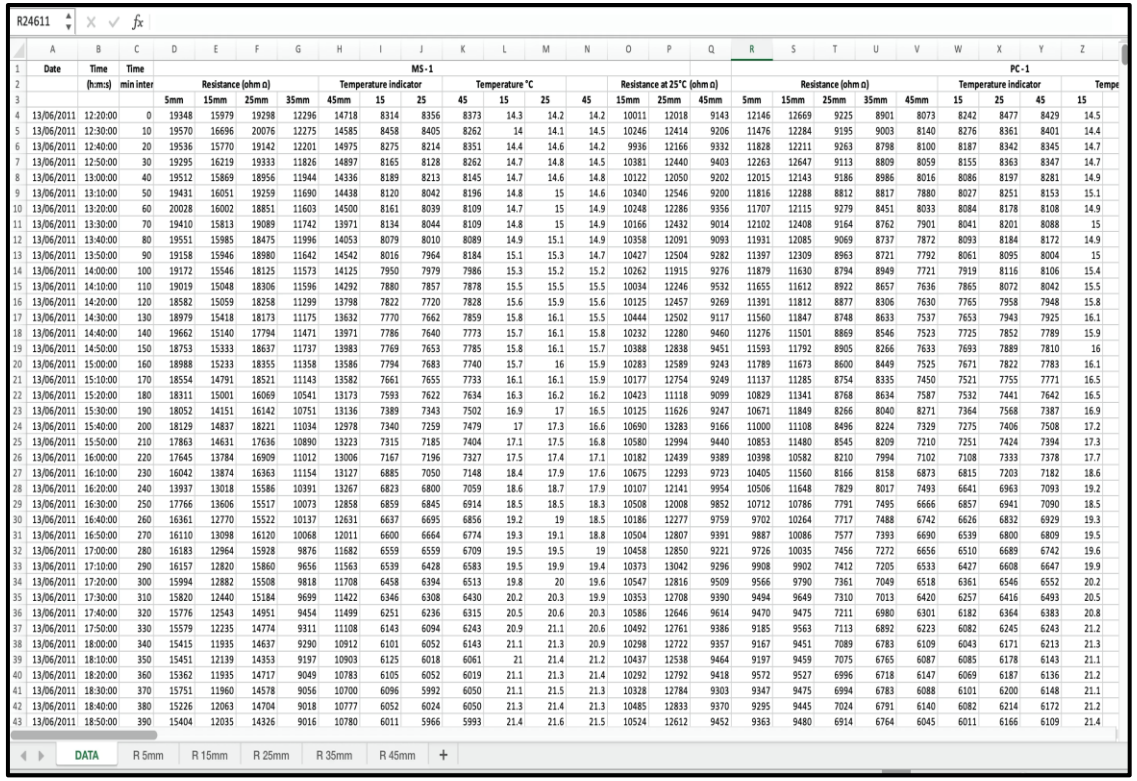
Problem Statement

Issues with the current practice of collecting massive uncertain sensor data sets:

- Difficult to process;
- Not easy to identify defects from noise;
- Wrong judgement could trigger untimely maintenance and/or repair, resulting in an increased cost of maintenance.

Potential solution:

Apply AI-enhanced SHM methodology for data processing and decision making, thereby for better in-service performance assessment of structures.



Date	Time (h:m:s)	Time min inter	MS-1 Resistance (ohm Ω) 5mm	15mm	25mm	35mm	MS-1 Temperature indicator 45mm	15	25	MS-1 Temperature °C 45	15	25	45	MS-1 Resistance at 25°C (ohm Ω) 15mm	25mm	45mm	PC-1 Resistance (ohm Ω) 5mm	15mm	25mm	35mm	45mm	PC-1 Temperature indicator 15	25	45	15	Tempe
13/06/2011	12:20:00	0	19348	15979	19298	12296	14718	8314	8356	8373	14.3	14.2	14.2	10011	12018	9143	12146	12669	9225	8901	8073	8242	8477	8429	14.5	
13/06/2011	12:30:00	10	19570	16696	20076	12275	14585	8458	8405	8262	14	14.1	14.5	10246	12414	9206	11476	12284	9195	9003	8140	8276	8361	8401	14.4	
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13/06/2011	18:50:00	390	15404	12035	14326	9016	10780	6011	5966	5993	21.4	21.6	21.5	10524	12612	9452	9363	9480	6914	6764	6045	6011	6166	6109	21.4	

Application of Artificial Intelligence in SHM

AI-based algorithms are used to:

- enhance building performance and early detection of the deterioration of structures.
- To identify, locate and quantify defects.
- To assess structural health conditions.
- To capture changes in natural vibration frequencies and mode shape.

Gap –No such system has been used to extract reliable information of material properties from the sensor data and thereby to capture their changes for prognosis/decision making and predict the in-service performance of structures.

Objectives of the research

To **apply Artificial Intelligence to SHM data obtained from electrical resistance sensors** and thereby to demonstrate the advantage of this method over manual data analysis for assessing the performance of concrete in service.

Experimental Details

- Three high-performance concrete (HPC) mixes with two samples of each mix, including Portland cement (PC), pulverised fuel ash (PFA) and micro-silica (MS).
- Concrete blocks (410 x 100 x 250mm) embedded with temperature and resistivity sensors.
- Blocks were exposed in an open area one metre apart from a 3-storey building in Belfast.

Concrete Mix Proportions

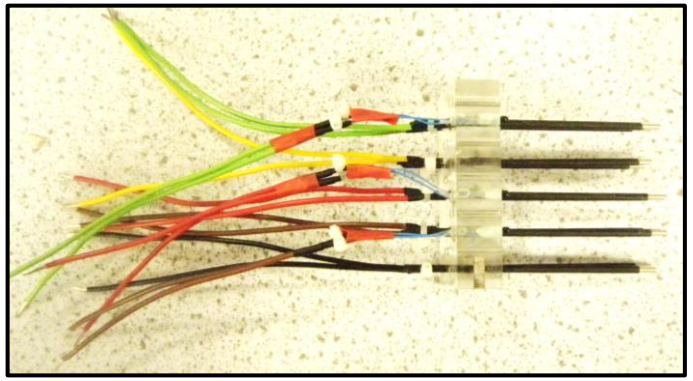
HPC	Binder proportions (% by mass)	Material quantities (kg/m^3)						w/b ratio	SP
		PC	MS	PFA	Water	Fine aggregate	Coarse aggregate		
PC	100:0 Only PC	485	0	0	145	689	1150	0.3	1.3
PFA	80:20 PC: PFA	388	0	97	145	668	1150	0.3	1.4
MS	73:7:20 PC: MS: PFA	352	36	97	145	652	1150	0.3	1.5

Specimens at the exposure environmental conditions

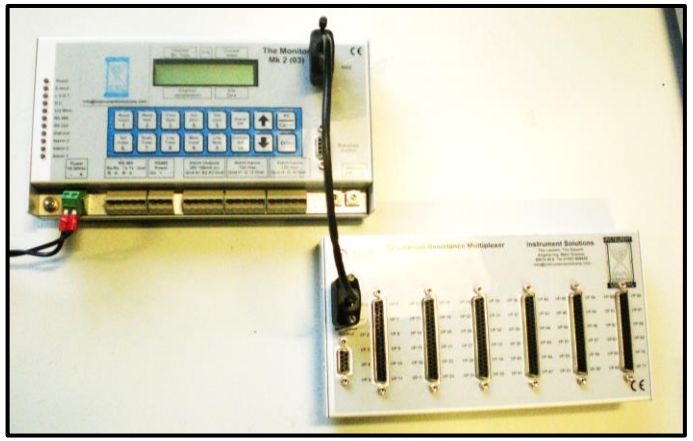
Experimental Details

- HPC blocks embedded with a multielectrode array for:
  - acquiring **electrical resistance**
  - thermistors for **temperature measurements**.
  - 3 different depths 15, 25 and 45mm
- Data was recorded every 10 minutes for 6 months.
- Over 24000 sets of data in total.
- **Data wrangling-** Raw data was converted into a useful and suitable format for analysis.
- **Data cleaning -** Missing values, duplication of data, invalid data, and noisy data were identified and removed to reduce their influence.

Sensors embedded in concrete blocks



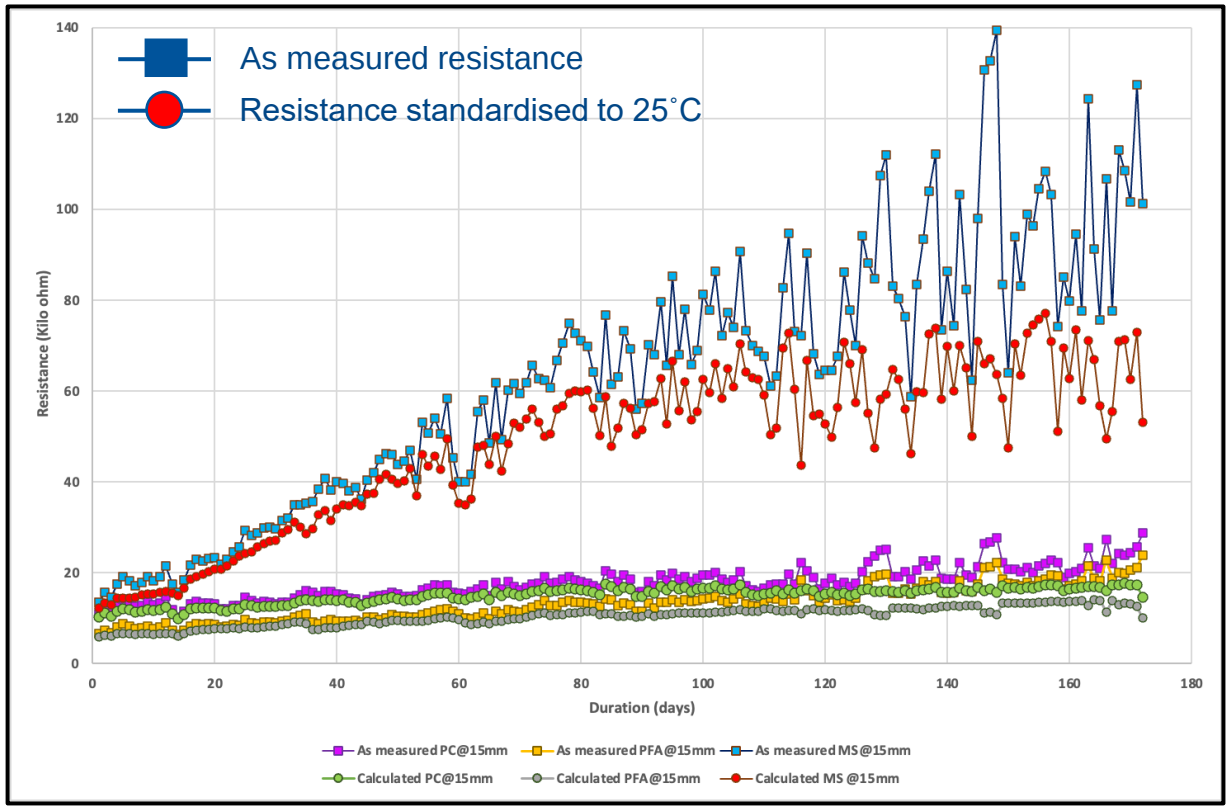
Monitoring system



Correction of Resistance Data for Temperature

- Huge diurnal variation in resistance for all concrete types.
- “Resistance is a temperature-dependent function” (Nanukuttan, et al., 2017).
- Arrhenius relationship to remove the influence of temperature on electrical resistance.
- The acquired values of activation energy enables resistance measurements to be standardised to 25°C.
- Huge fluctuations in as-measured resistance are slightly reduced in standardised resistance, especially for MS.

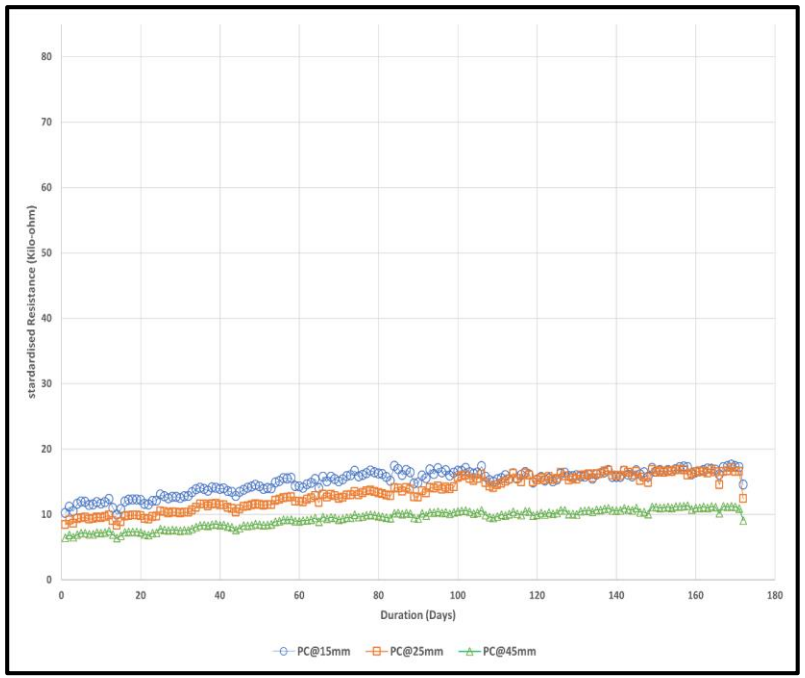
As measured resistance vs standardised resistance (KΩ)@25˚C for PC, PFA and MS at 15mm depth

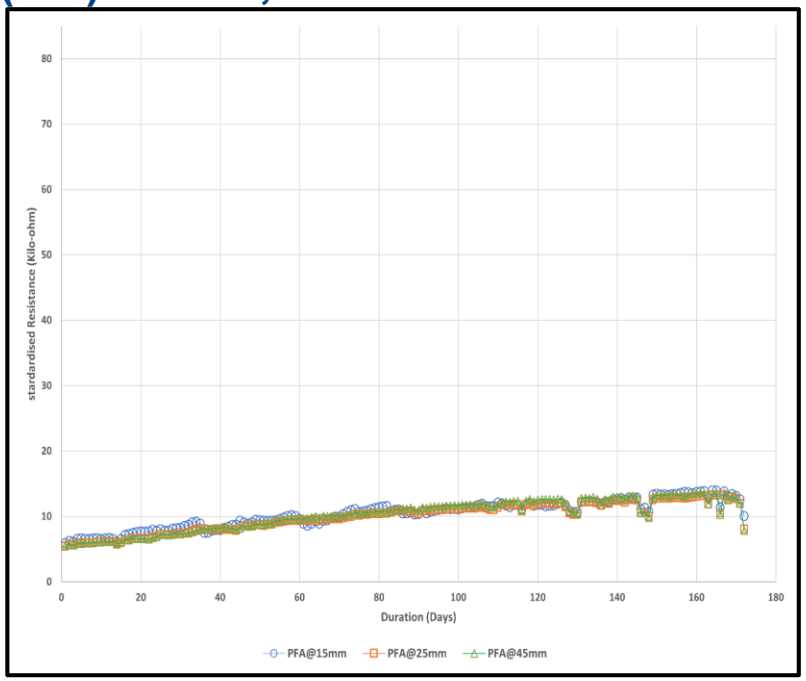


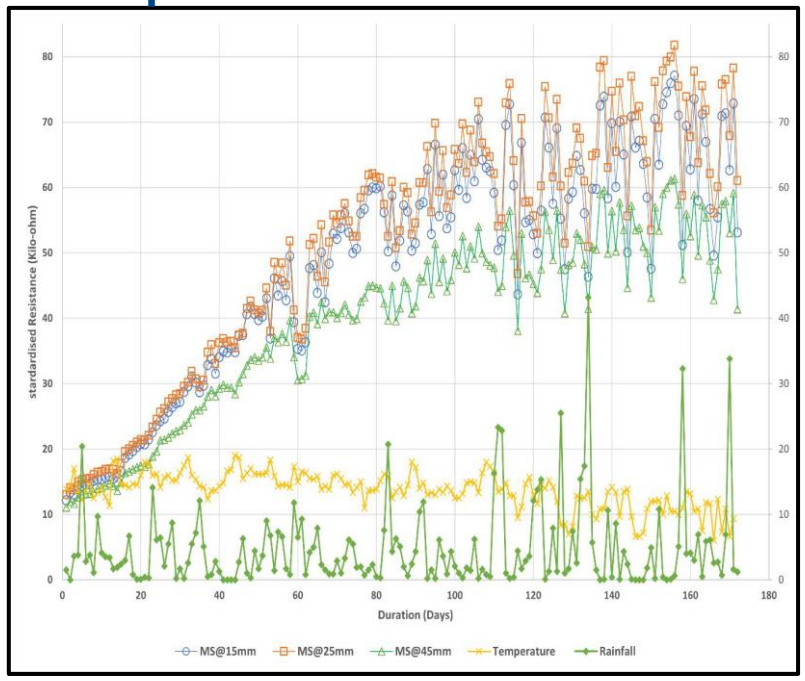
Initial Observations from the Standardised Data

- Resistance increased over the period in all three concrete types (Resistance increase with the pozzolanic reaction of the binder material).
- Resistance at deeper concrete is lower than at the surface (surface release more moisture).

Standardised resistance (KΩ) for PC, PFA and MS to a reference temperature of 25°C



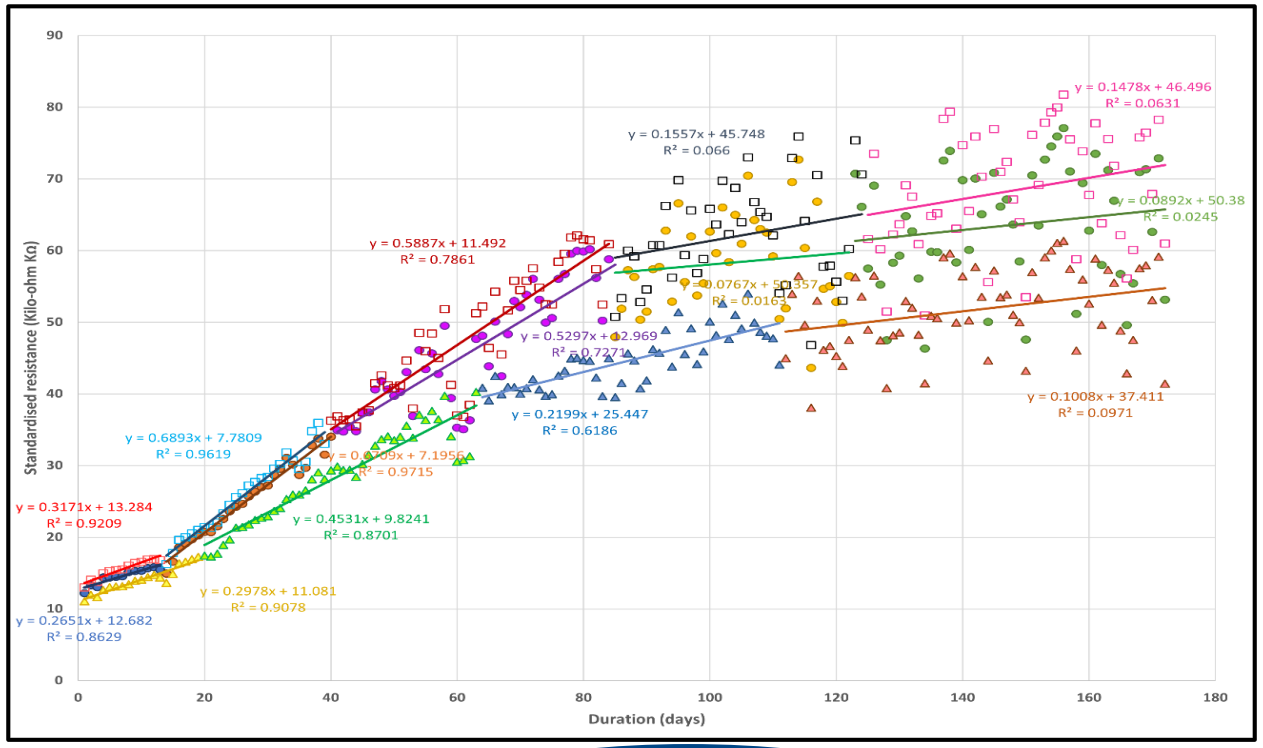




Manual Analysis of Data

- The performance of concrete is assessed based on electrical resistance and chloride diffusivity calculated from electrical resistance.
- Important to evaluate resistance values for all concrete types to derive diffusion coefficients for predicting the service life.
- Three parameters of resistance to discuss:
  - Initial rate of increase in resistance,
  - Value of stable resistance,
  - Time taken to reach a stabilised resistance value.

Manual piecewise regression of resistance for MS

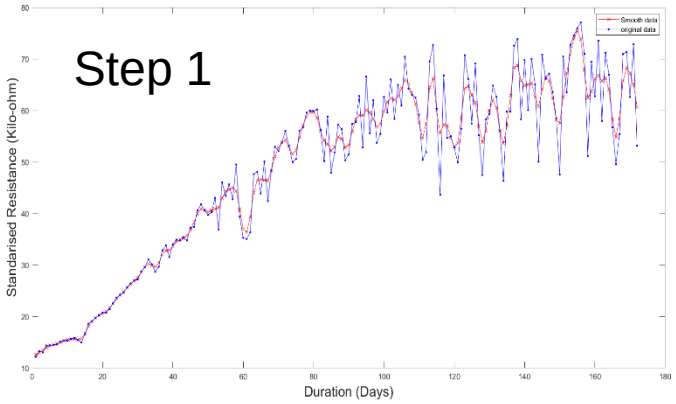


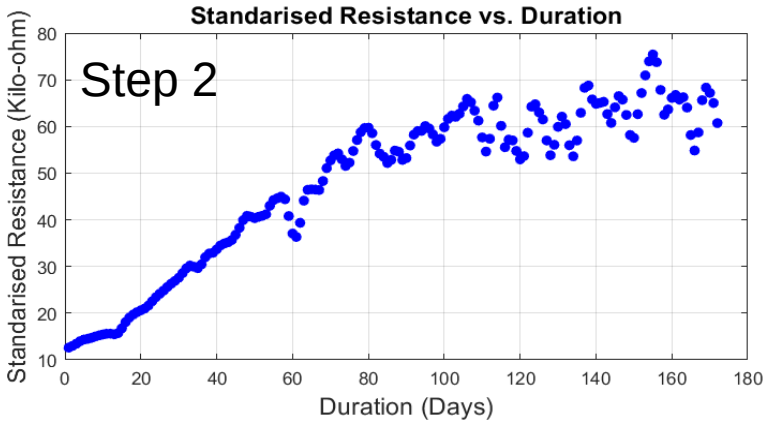
Easily understandable

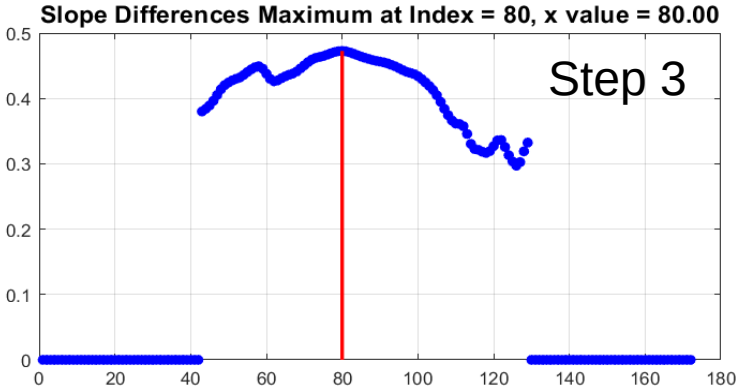
Difficult to identify ultimate breakpoint

Time consuming

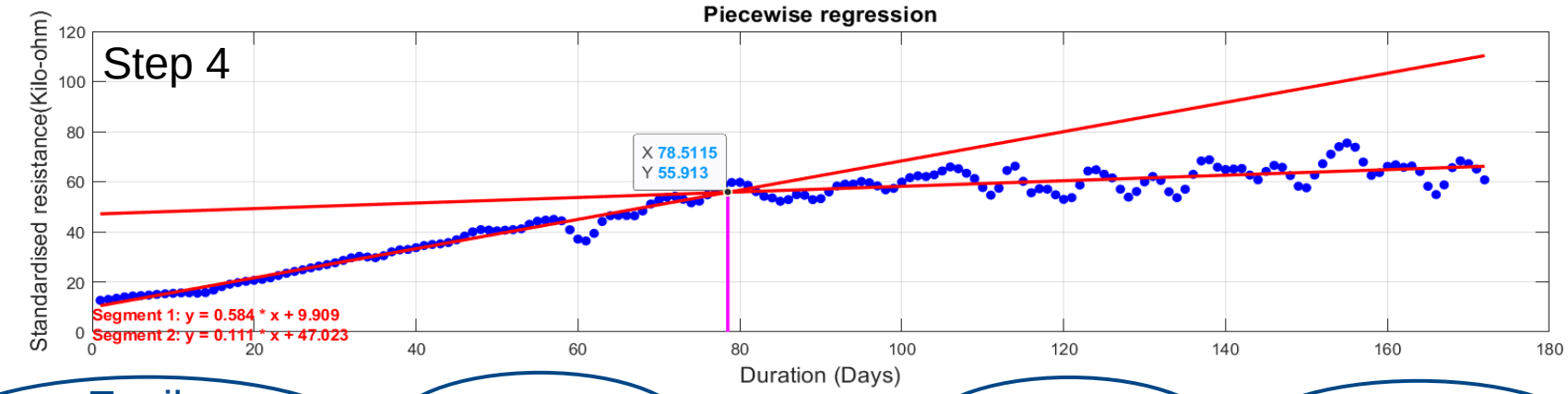
Application of AI to SHM Data







- "Gaussian weighted moving average filter" to smooth the data.
- Automated piecewise linear regression to determine change in resistance gradient and stabilised value.



Easily understandable

Faster

Reliable

Easily Interpretable

Results and Discussion

- Initial rate of increase in resistance

  MS > PFA > PC

- Time taken to stabilise

  MS > PFA > PC

- Determined diffusion coefficient using the relationship $\frac{De}{D_0} = \frac{\rho}{\rho_{bulk}}$ which could be used to predict the service life.
- Diffusion coefficient had a trend opposite to that for resistance

Resistance/diffusion coefficient values using AI-enhanced approach

Concrete Mix	Depth (mm)	Initial rate of increase in resistance (%)	Time taken to stabilise (days)	Stabilised value (KΩ)	Diffusion coefficient (m^2/s)
PC	15	051.0	66.1	15.41	4.10×10^{-11}
	25	091.5	129.0	16.13	5.20×10^{-11}
	45	051.8	77.0	09.73	7.64×10^{-11}
PFA	15	065.4	57.1	09.79	8.72×10^{-11}
	25	096.7	83.7	10.73	8.55×10^{-11}
	45	110.0	93.9	11.68	9.32×10^{-11}
MS	15	359.9	78.5	55.91	3.33×10^{-11}
	25	348.8	78.1	58.25	2.20×10^{-11}
	45	246.2	64.0	40.32	4.91×10^{-11}

Conclusions

- The challenge identified in handling, smoothing and analysing large data set manually demonstrated the need to resort to **Artificial Intelligence** for data analysis.
- The proposed methodology of applying AI to SHM data is **faster and more efficient** than the conventional approach to calculate the stabilised value of resistance/diffusion coefficient.
- Data highlighted the impact of temperature and depth on resistance measurements for different concrete mixes.
- Both the standardised resistance values and the diffusion coefficient calculated from resistance clearly demonstrated the benefit of using supplementary cementitious materials in improving the durability of concrete.
- The AI-enhanced methodology represents a **reliable, easily interpretable and effective approach** that can be used for different types of concrete in structures for monitoring and the calculation of resistance/ diffusion coefficient and thereby predict the performance of concrete structures.

Recommendations for Future Work

- Use long-term data to assess the effect of exposure environment on durability of concrete using electrical resistance sensors.

- Install RH sensors both inside and outside of concrete and the temperature sensors outside the concrete in addition to inside the concrete so that any influence of the ambient environmental conditions around the concrete surface on measured resistance can be determined.

- The proposed methodology to smooth noisy data and extract reliable information from large amount of resistance data may be repeated for other concrete types and exposure conditions. However, the smoothing window would change depending on the noise and type of analysis.

Thank You.
Any Questions?

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