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5 - 8 DECEMBER 2022
DUBAI WORLD TRADE CENTRE

Applications of Artificial Intelligence and Machine Learning in Geotechnical Engineering

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IRC

About this Presentation

1. Overview of Artificial intelligence (AI) and Machine Learning (ML)

2. AI in Geotechnical engineering - Examples of applications :

   - Scale of Construction sites
   - Laboratory scale
   - Micro - scale

3. Benefits and Limitations of AI

Overview of AI and ML

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Overview of AI and ML

What exactly is AI?

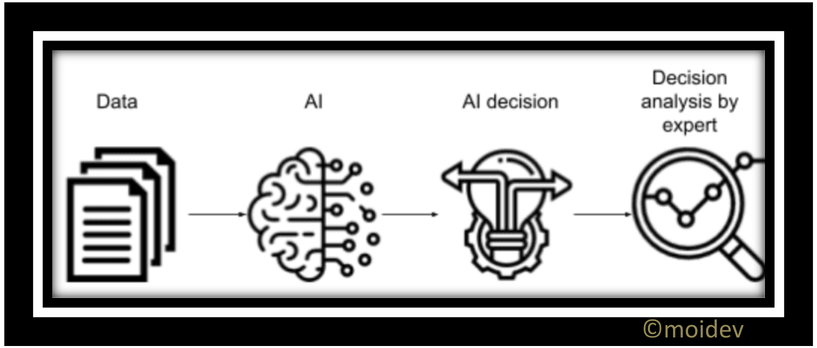
AI is a computational technique that attempts to mimic, in a very simplistic way, the human cognition ability (e.g. brain, genes, nerve system) to think and learn on its own.

It is a simulation of human intelligence into machines to do tasks that we would normally rely on humans to perform.

Overview of AI and ML

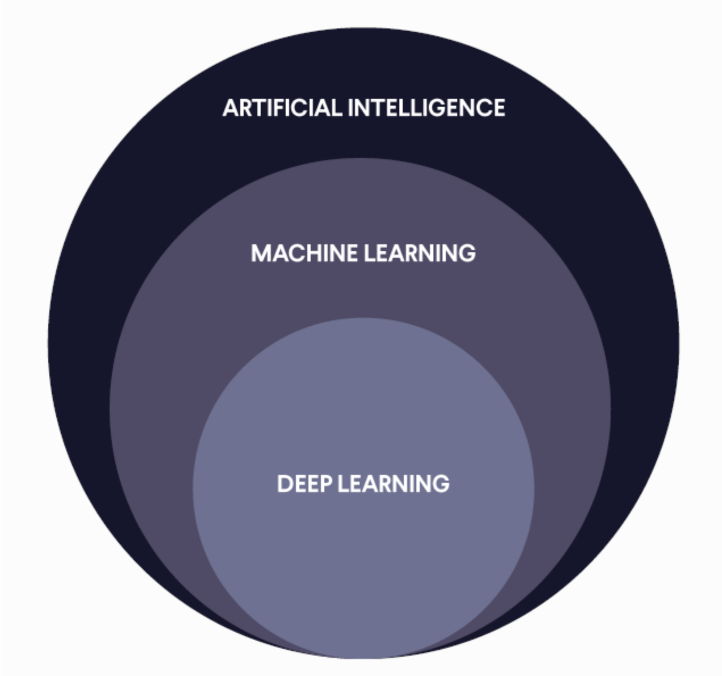
What exactly is AI?

AI models are data-driven models which means that they rely on the data alone to determine the structure of a phenomenon (or system) without the need for assumptions or simplifications about that system, which is in contrast to most physically-based modelling techniques.



Overview of AI and ML

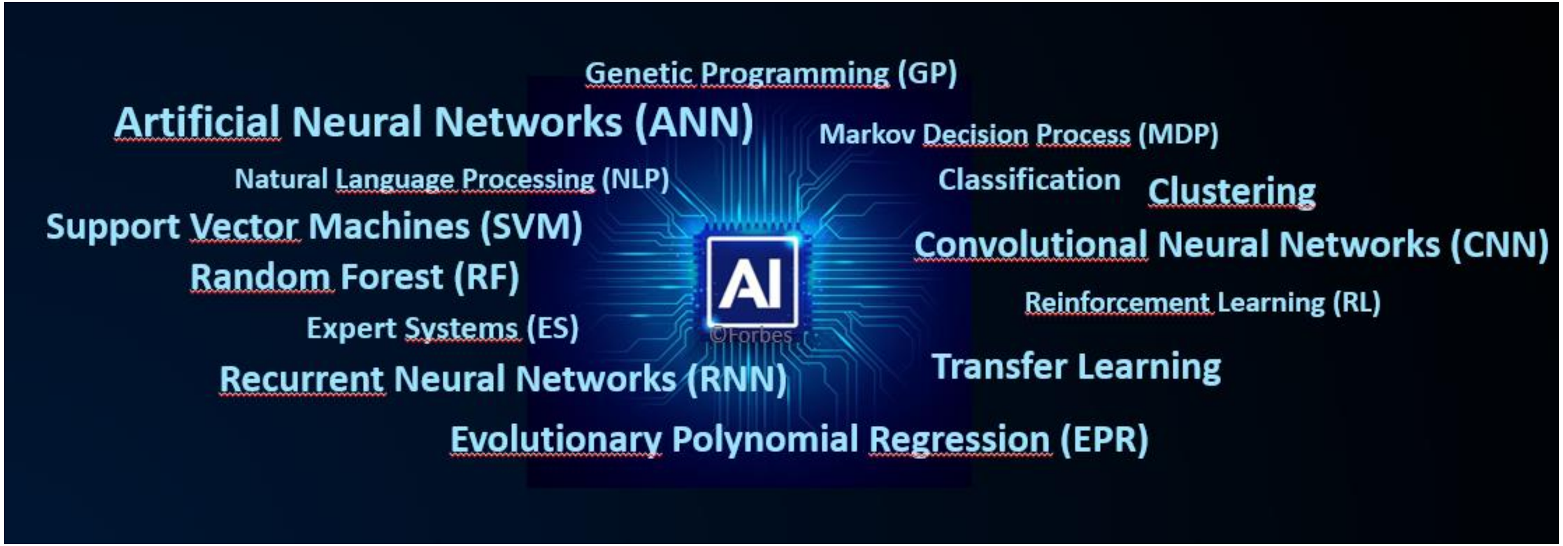
AI and ML



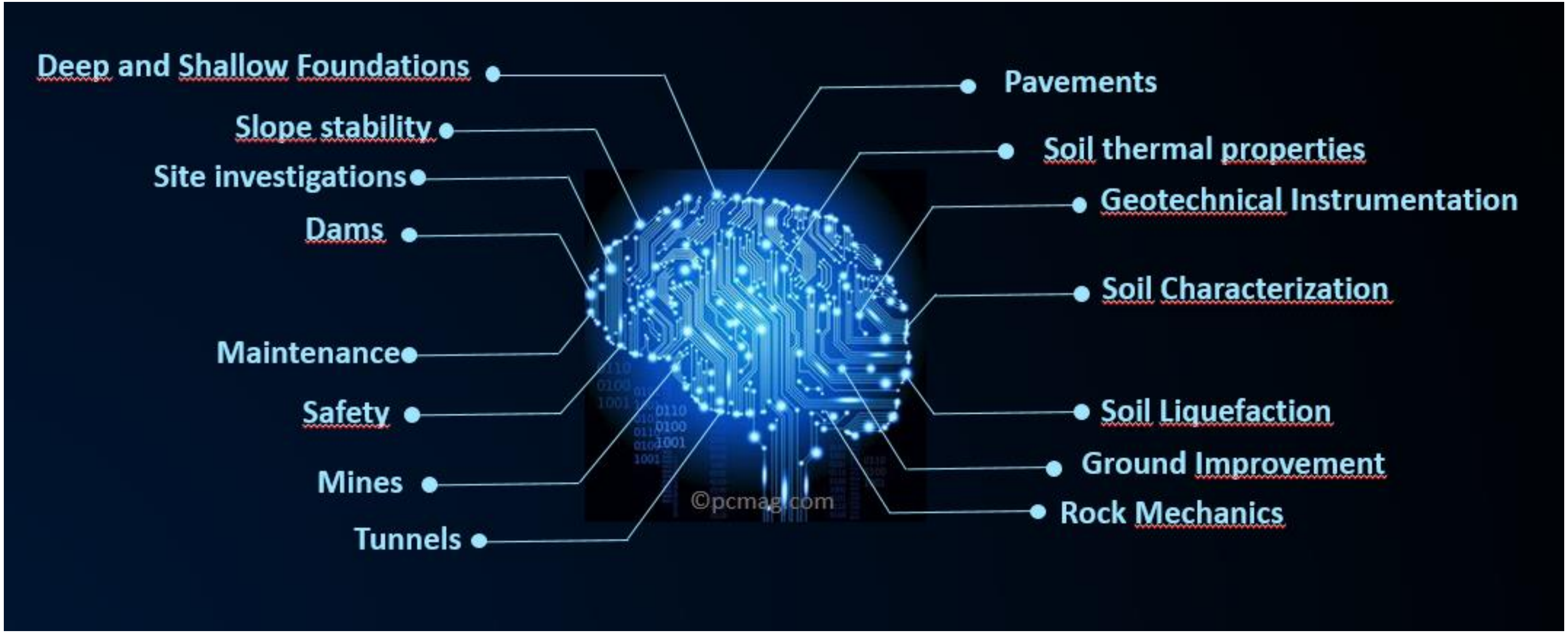
AI refers to the capability of a machine to perform a certain behavior; while ML is the algorithm that learns patterns from datasets to predict future outcomes, recognize patterns, or suggest different classes to the data.

Overview of AI and ML

Major AI Techniques



AI in Geotechnical Engineering



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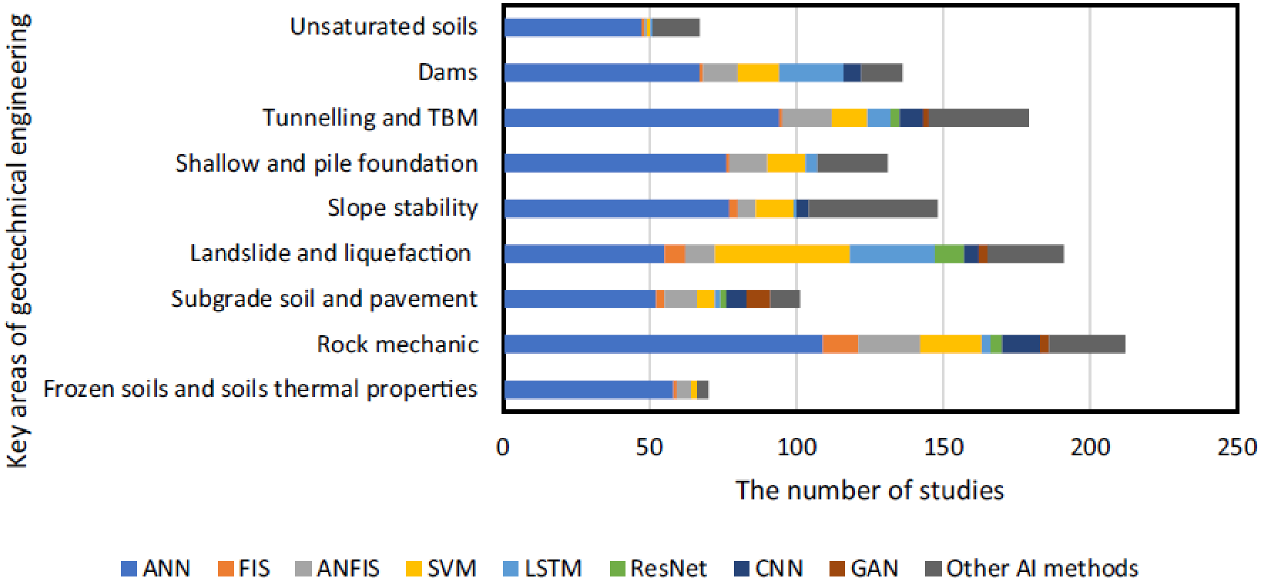
The use of different AI techniques in some applications in geotechnical engineering



Beghbani, A., Choudhury, T., Costa, S., Reiner, J. (2022). "Application of artificial intelligence in geotechnical engineering: A state-of-the-art review" *Earth-Science Reviews 228*, https://doi.org/10.1016/j.earscirev.2022.103991.

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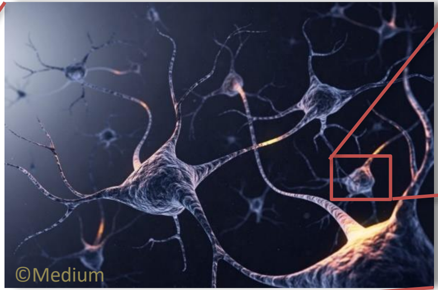
Artificial Neural Networks

Concept

©TheEconomicTimes



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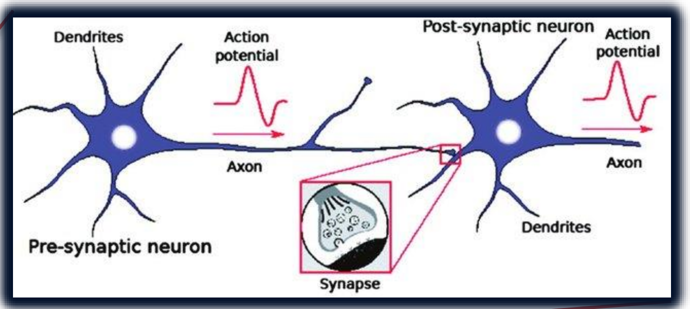

©book: Memristor and Memristive Neural Networks

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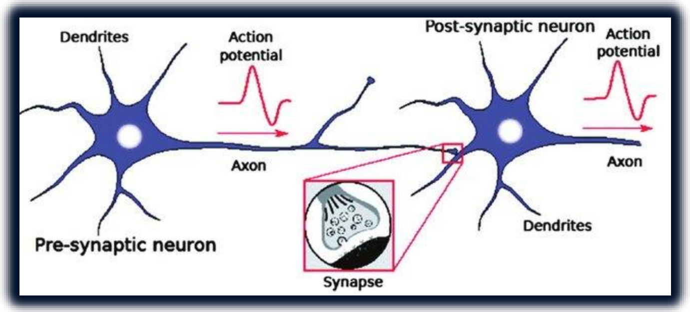
Artificial Neural Networks (ANN)

Concept



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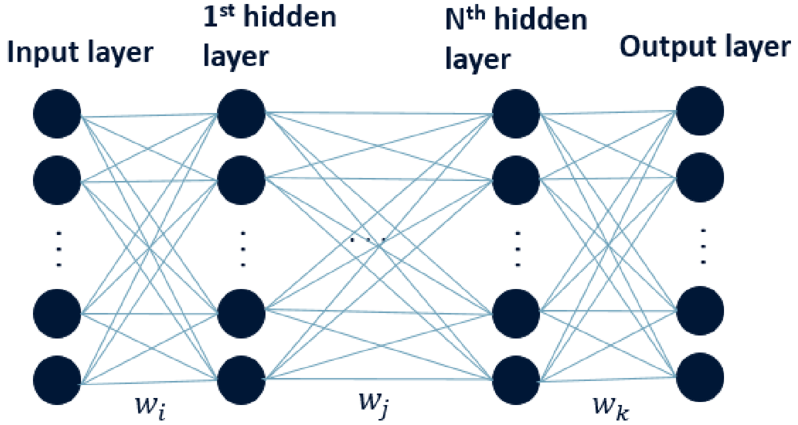
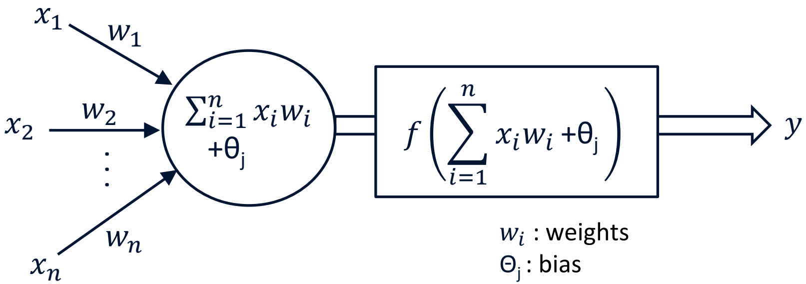


Perceptron



w_i : weights
Θ_j : bias

Examples of Applications:

Scale of Construction Sites

Dam Safety

https://www.hdrinc.com/insights/digital-twin-diablo-dam-comes-life

The Diablo Dam was built in 1936 along the Skagit River in northwestern Washington.

To ensure the dam's safety, a digital twin (virtual replica of the dam) was created merging real data obtained with embedded sensor network and incorporating machine learning and artificial intelligence to perform predictive analysis and determine how asset and geotechnical conditions would change with time (such as natural shifting, erosion of the surrounding soil, automatically identify cracks and spalls) allowing operators to take corrective actions to immediately improve their targeted maintenance scheduling and help ensure safe operations.

AI in Geotechnical Engineering

Examples of Applications

Slope Stability

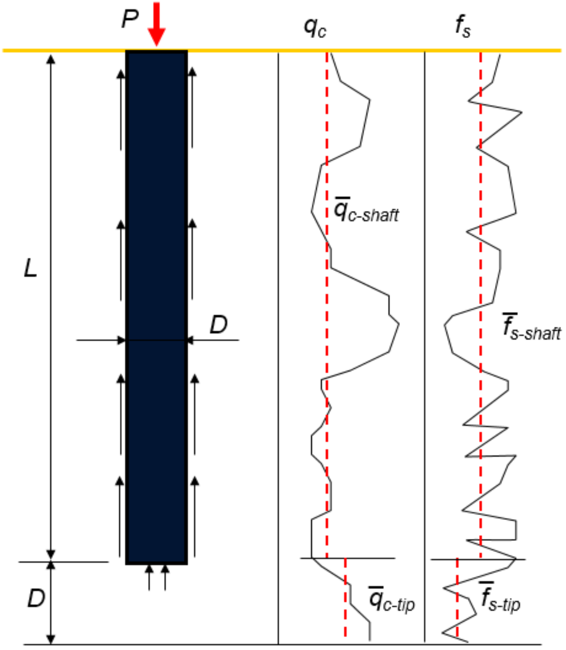
Safety on Construction Sites

- Real time monitoring of the site
- Plan ahead for optimum slopes
- Identify any misuse of personal protective equipment (e.g. safety helmet or vest)
- When a dangerous act is predicted, the system will alert the safety officer and inspector to avoid injuries

AI in Geotechnical Engineering

Examples of Applications

Prediction of the load-settlement curve of Driven Piles



Driven pile

Several in-situ full-scale pile load tests, as well as cone penetration test (CPT) data were used to develop AI model.

The tests were conducted on sites of different soil types and geotechnical conditions, ranging from cohesive clays to cohesionless sands including layered soils

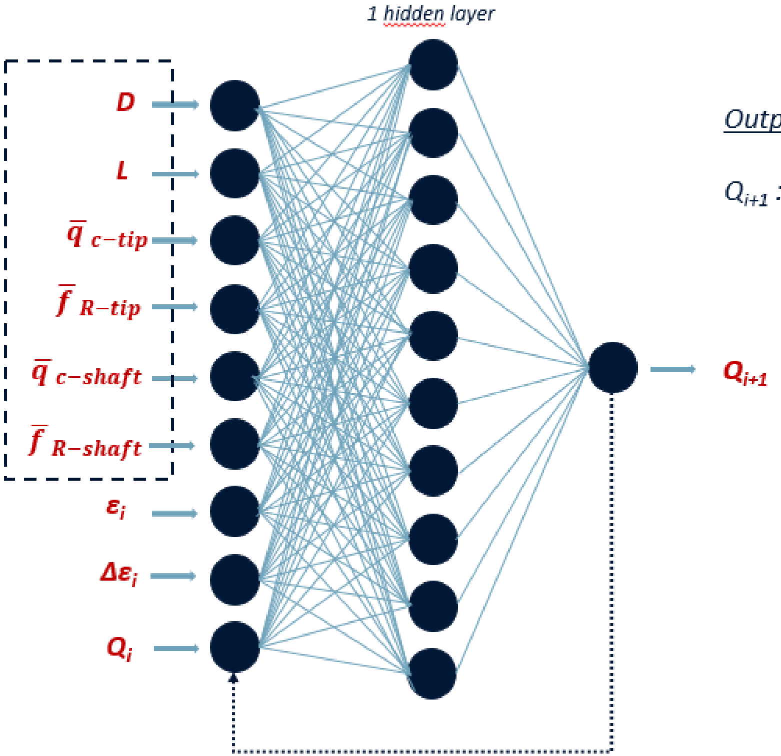
Shahin, M. A. (2014). "Load-settlement modelling of axially loaded drilled shafts using CPT-based recurrent neural networks." *International Journal of Geomechanics*, ASCE, 14(6), 06014012(1-7).

Shahin, M. A. (2014). "Load-settlement modelling of axially loaded steel driven piles using CPT-based recurrent neural networks." *Soils and Foundations*, 54(3), 515-522.

Prediction of the load-settlement curve of Driven Piles

Input parameters at current state:

D: equivalent diameter(mm)
L : pile embedment length (m)
$\bar{q}_{c-tip}$: weighted average cone point resistance over the pile tip failure zone
$\bar{f}_{R-tip}$: weighted average friction ratio over the pile tip failure zone
$\bar{q}_{c-shaft}$: weighted average cone point resistance over the pile embedmeent length
$\bar{f}_{R-shaft}$: weighted average friction ratio over the pile embedment length
ε_i : normalized axial settlement (%)
$\Delta\varepsilon_i$: increment in axial settlement (%)
Q_i : pile load (kN)



Output at next loading state:

Q_{i+1} : pile load (kN)

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Examples of Applications

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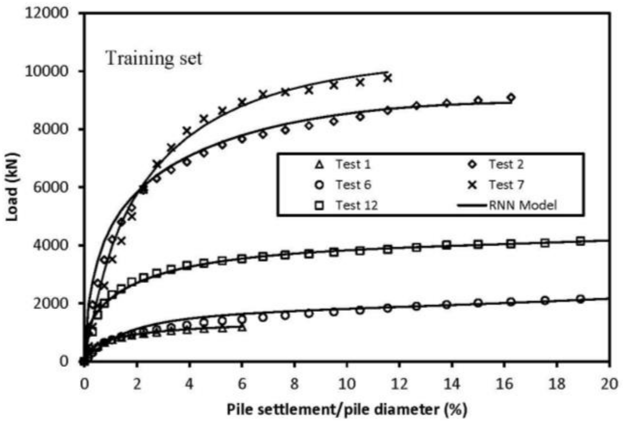

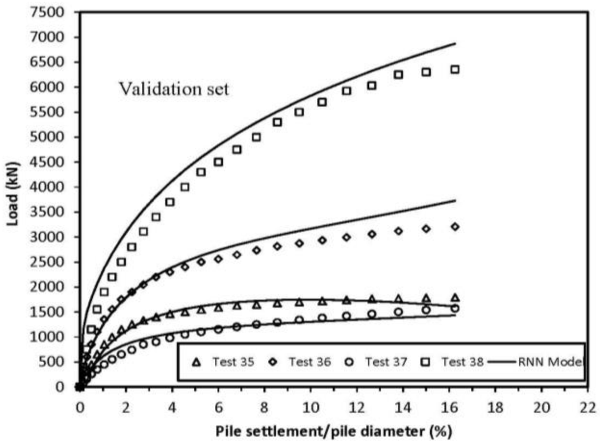

Performance measure	Training	Validation
Coefficient of correlation, *r*	**0.997**	**0.994**
Coefficient of Determination, R^2	**0.993**	**0.974**

Shahin, M. A. (2014). "Load-settlement modelling of axially loaded drilled shafts using CPT-based recurrent neural networks." *International Journal of Geomechanics*, ASCE, 14(6), 06014012(1-7).

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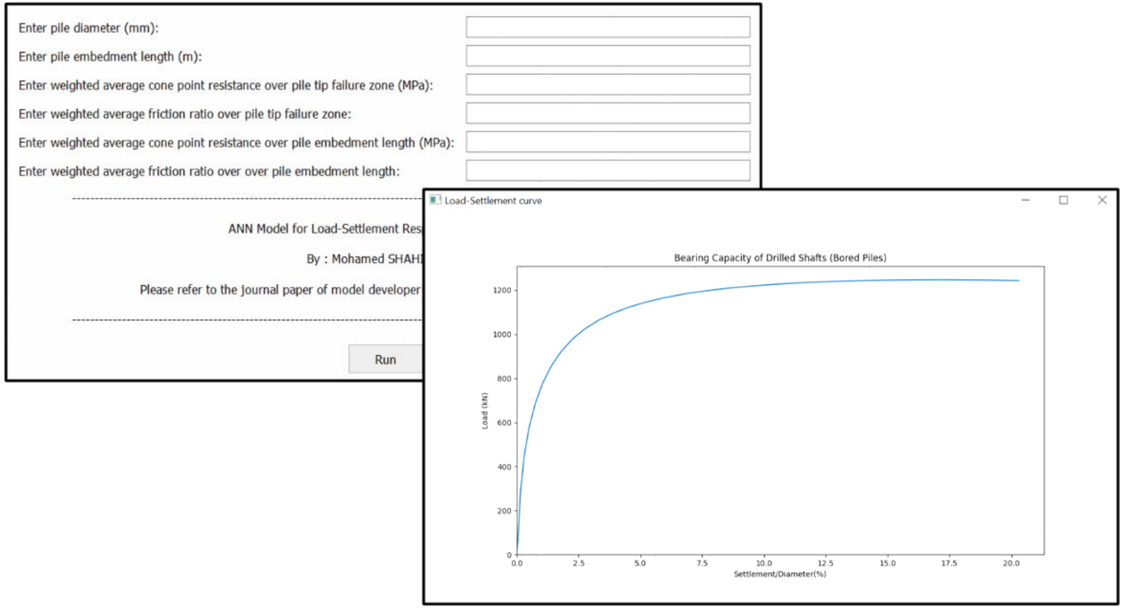
Examples of Applications

Prediction of the load-settlement curve of Driven Piles

How engineers can use the developed AI model?

AI models can be used to establish a relationship between inputs and outputs which can be implemented in a simple user-friendly application.



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Examples of Applications:

Laboratory Scale

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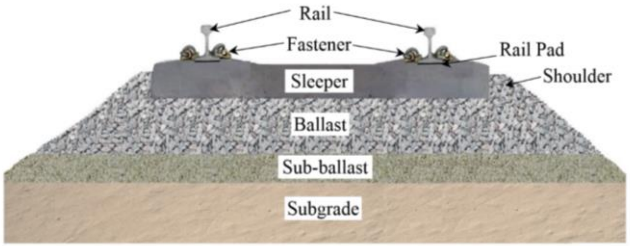
Examples of Applications

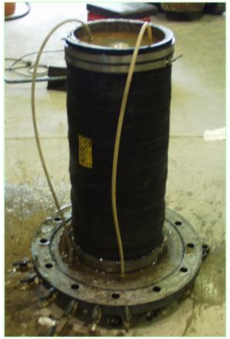
Prediction of the Mechanical behavior of Railway Ballast



Large-scale triaxial apparatus

Diameter = 300 mm

Height = 600 mm

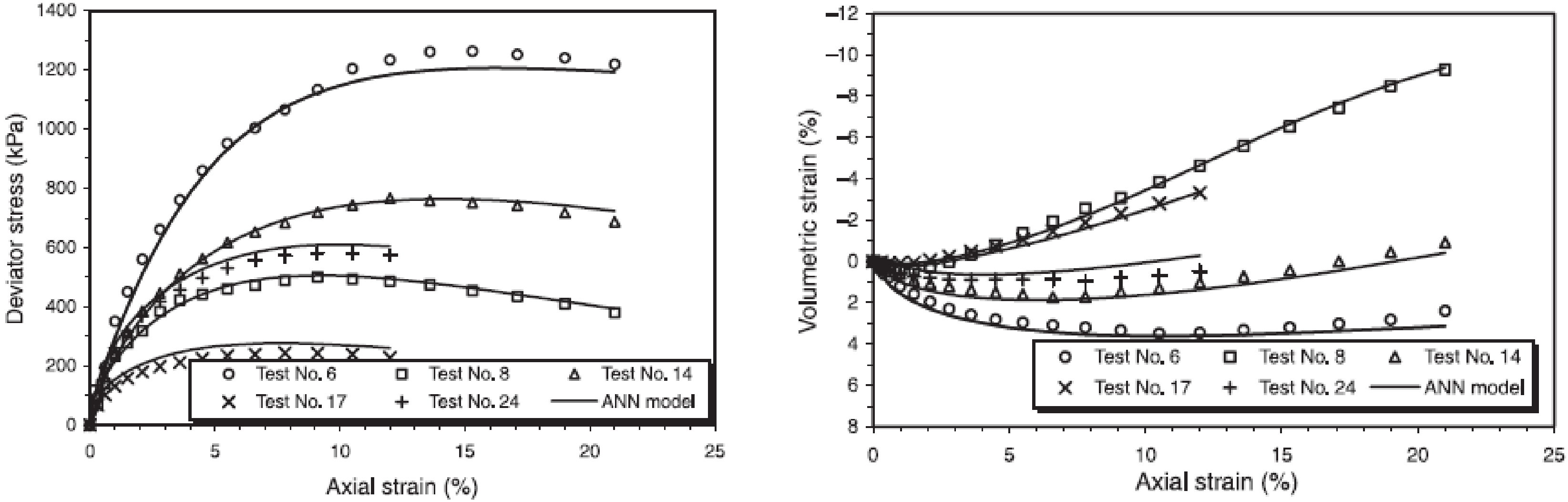


__AI Model Features:__

D_{50} : diameter at which 50% of the specimens pass through the sieve
C_u : coefficient of uniformity
C_c : coefficient of curvature
e: void ratio
Υ : bulk unit weight (kN/m^3)
σ_3: confining pressure
ε_i : axial strain (%)
$\Delta\varepsilon_i$: axial strain increment (%)
q_i : deviator stress (kPa)
$\varepsilon_{v,i}$: volumetric strain (%)

Shahin, M. A., Indraratna, B. (2006). "Modeling the mechanical behaviour of railway ballast using artificial neural networks", *Canadian Geotechnical Journal*, 43: 1144-1152.

Prediction of the Mechanical behavior of Railway Ballast



Shahin, M. A., Indraratna, B. (2006). "Modeling the mechanical behaviour of railway ballast using artificial neural networks", *Canadian Geotechnical Journal*, 43: 1144-1152.

Examples of Applications:

Micro - Scale

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Examples of Applications

Fabric and Effective Stress Distribution in Internally Unstable Soils

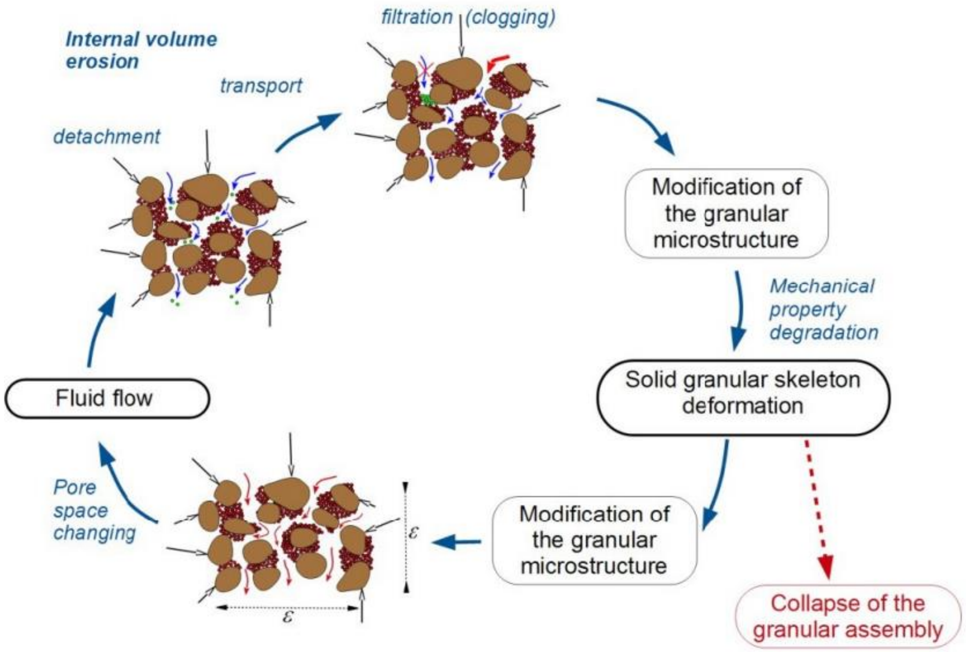
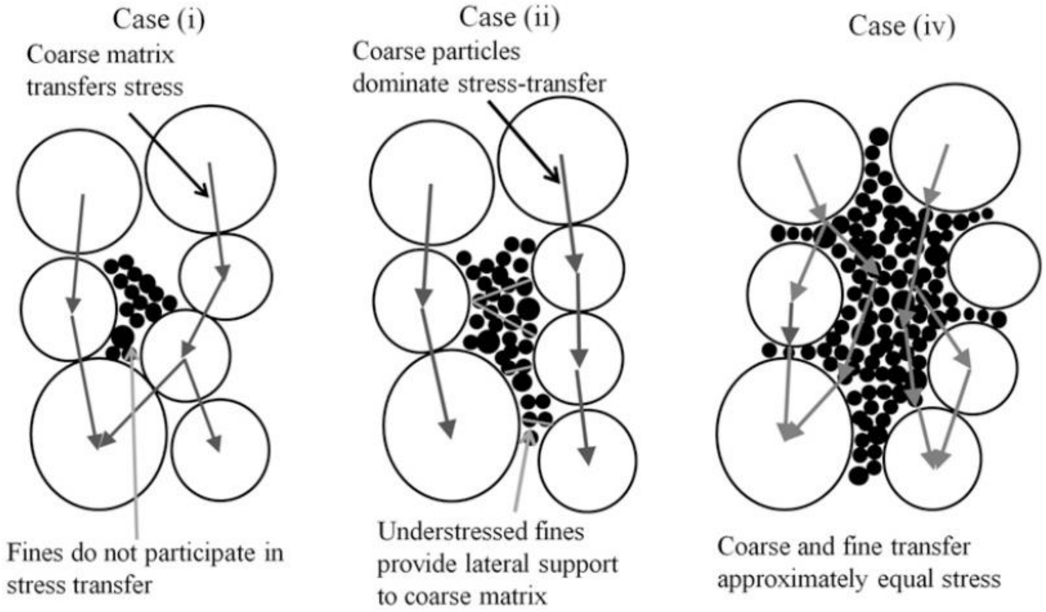


Illustration of the suffusion process (Sibille (2016)).

The collapse of Teton dam (Wikipedia)

Fabric and Effective Stress Distribution in Internally Unstable Soils



Different fabric cases (Shire et al. (2014))

Skempton and Brogan (1994) proposed that a stress-reduction factor, α, can be defined as the proportion of the overburden acting on the loose fraction in the no flow condition:

$$\sigma'_{fine} = \alpha\, \sigma'$$

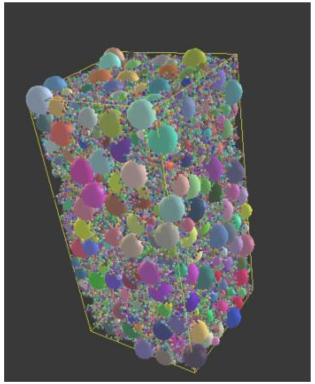
where σ'_{fine} is the effective stress transferred by the finer fraction; σ' overburden effective stress; and α is stress-reduction factor.

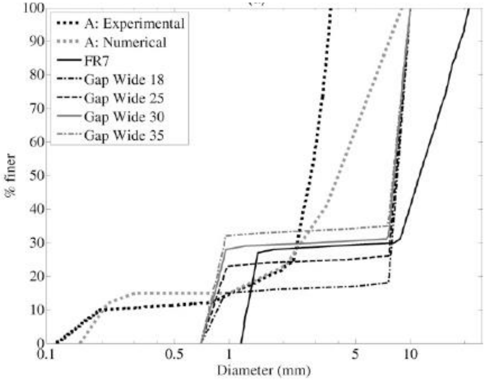
AI in Geotechnical Engineering

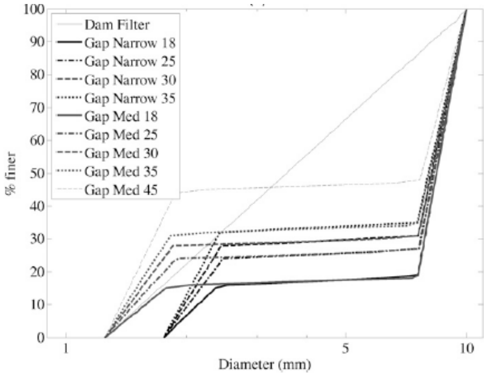
Examples of Applications

Fabric and Effective Stress Distribution in Internally Unstable Soils

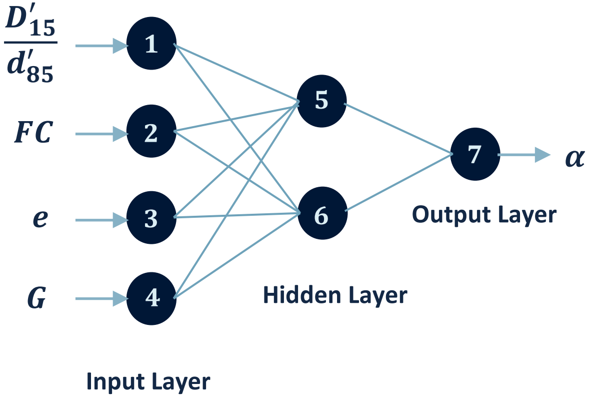
<u>Discrete element modeling</u>







<u>AI model</u>



<u>Model features:</u>

D'_{15}/d'_{85}: *D' represents the coarse fraction and d' represents the finer fraction*

FC *: Fines content (%)*

G : *Gap ratio*

e *: Void ratio*

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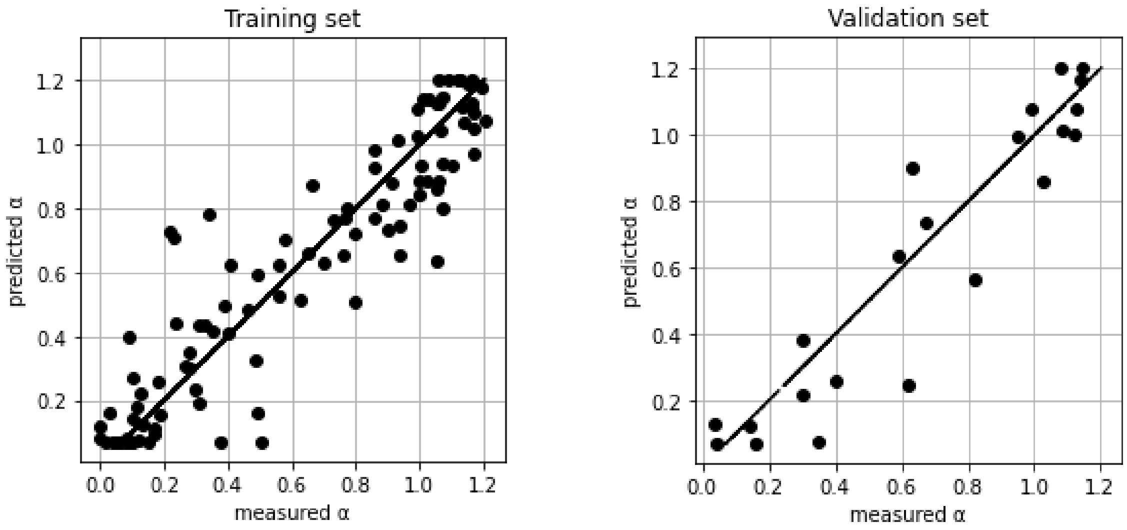
Examples of Applications

Fabric and Effective Stress Distribution in Internally Unstable Soils



Performance measures	**Training**	**Validation**
Coefficient of correlation, *r*	**0.924**	**0.917**
Coefficient of Determination, R^2	**0.853**	**0.852**

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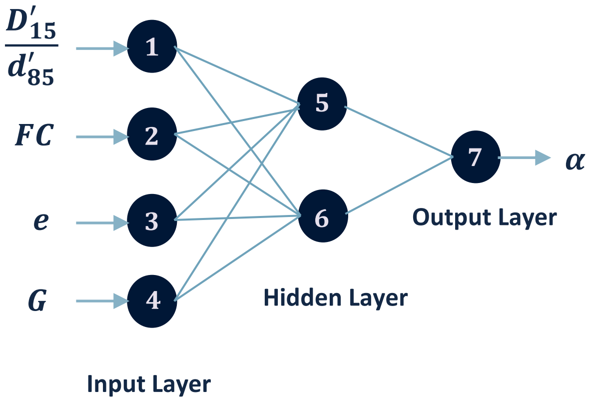
Examples of Applications

Fabric and Effective Stress Distribution in Internally Unstable Soils



$$\alpha = 5.46 + 4.48 tanh\, H_1 + 3.82 tanh\, H_2$$

$$H_1 = -0.08 - 9.6\frac{D'_{15}}{d'_{85}} + 0.71FC - 1.07e + 6.16G$$

$$H_2 = -1.81 - 3.62\frac{D'_{15}}{d'_{85}} + 7.73FC - 8.36e + 2.05G$$

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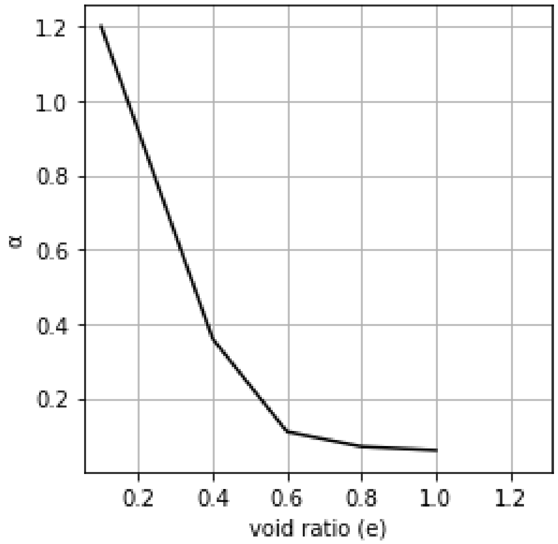
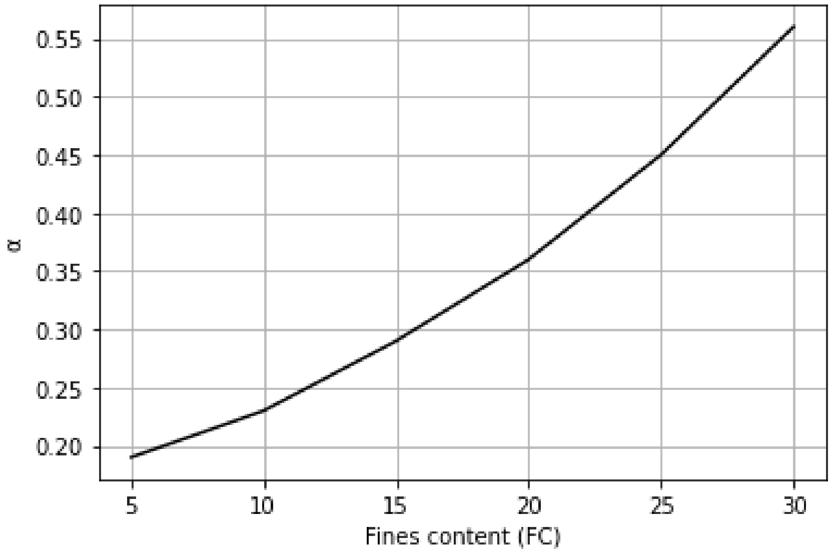
Examples of Applications

Fabric and Effective Stress Distribution in Internally Unstable Soils

Sensitivity analysis





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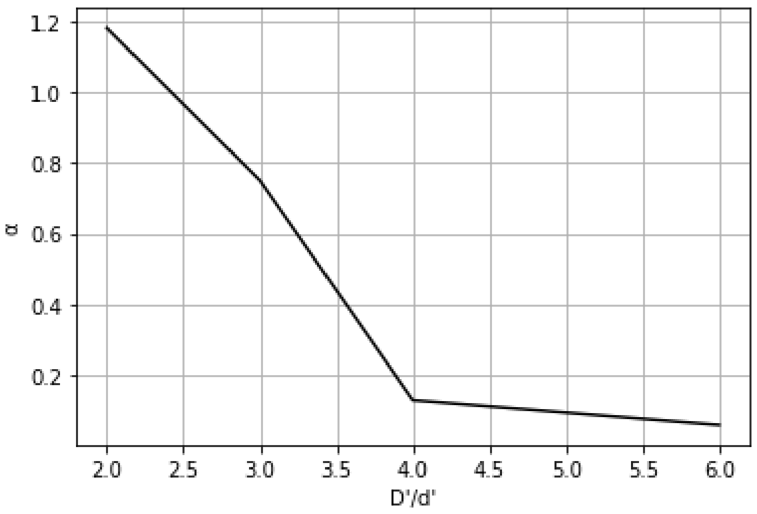
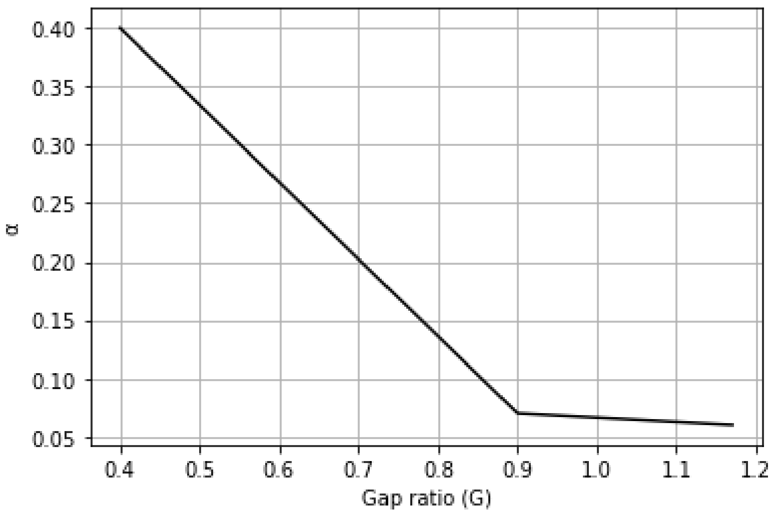
Fabric and Effective Stress Distribution in Internally Unstable Soils

Sensitivity analysis





The sensitivity analysis shows that the model is robust and able to reflect the role of important parameters compared to the available geotechnical knowledge

Benefits and Limitations of AI

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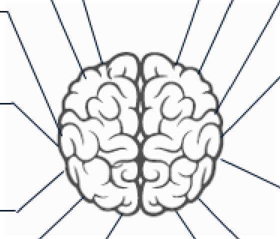
Benefits and Limitations of AI

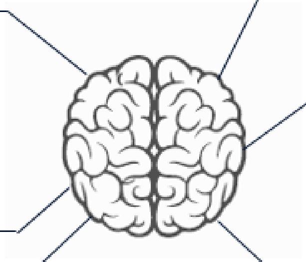
Benefits of AI



- Can solve highly non-linear complex engineering problems
- Can deal with multi-dimensional problems
- Can be updated
- Can deal with noisy, missing or uncertain data
- Lower chance of errors
- Enhance decision-making
- Optimize performance of assets
- Identify profitable opportunities
- Enhance security
- Avoid risks
- Allow for efficient management
- Provide accurate results
- Reduce the cost of construction
- Support predictive maintenance

Benefits and Challenges of AI

Limitations and Challenges



- Criticized of being black boxes
- Extrapolation is questionable
- Trial-and-error approaches
- Reliability of data
- Getting people on board
- Changing entire processes is not simple

Acknowledgements

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Prof. Mohamed Shahin (Curtin University, Australia)

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