

Un macro-elemento POD-TANN per la risposta orizzontale ciclica di un monopalo in argilla

XII Incontro Annuale dei Giovani Ingegneri Geotecnici - Padova

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POLITECNICO
MILANO 1863



Indice

Introduzione

POD & TANN

Caso investigato

Database e addestramento

Risultati

Conclusioni

Introduzione

<https://orsted.com/> (DONG)



Vindeby, 1991.
€7 milioni
 \approx 5MW
Dan

<https://orsted.com/>



Hornsea, 2018.
£4.6 miliardi
 \approx 1.2GW (One)
Eng

Progetto di due
substations



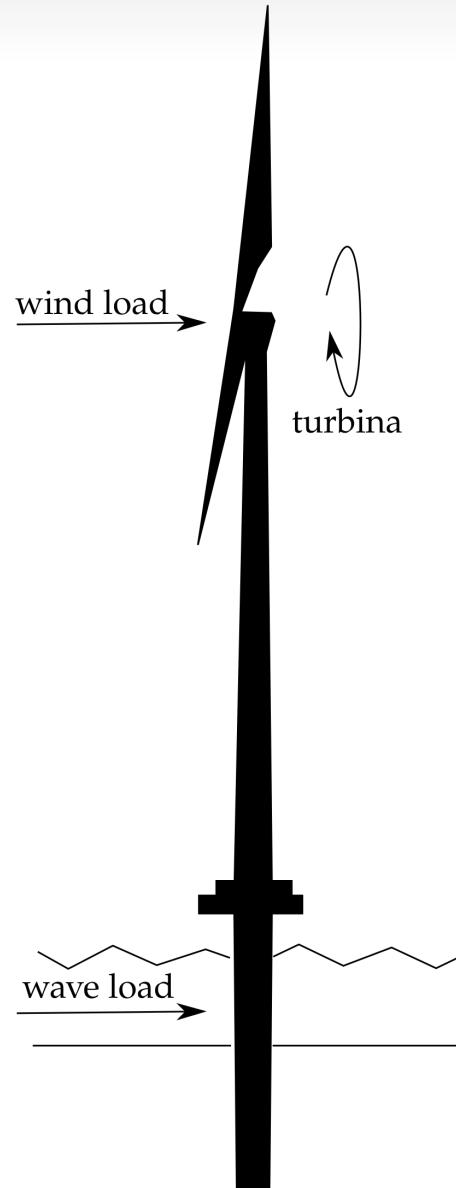
doggerbank.com



Dogger Bank, 2023.
€6 miliardi
 \approx 3.5GW
Eng

Approcci di modellazione

Azione primaria da considerare per il progetto SLU: **carico ciclico**.



Fattori da considerare

- Comportamento isteretico del terreno
- Interazione palo-terreno
- Comportamento a fatica
- Influenza dell'installazione
- Ratcheting
- ...

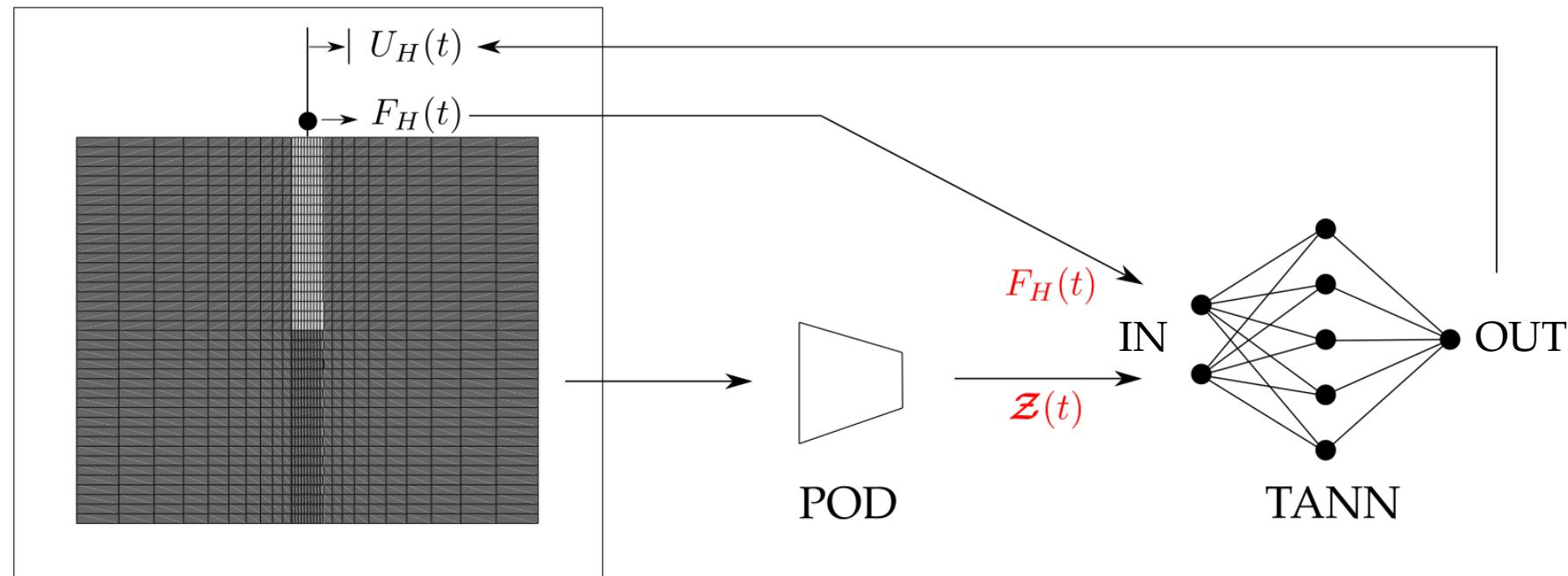
Metodi empirici: LeBlanc et al. 2010, Little and Briaud 1988; Poulos 1982

Fattori di sicurezza: DNV 2014; API 2010

Metodi numerici (FEM): Liu et al. 2022, Staubach and Wichtmann 2020

Curve p-y: Kementzetzidis et al. 2022, Zhang et al. 2020.

Macroelemento POD - TANN



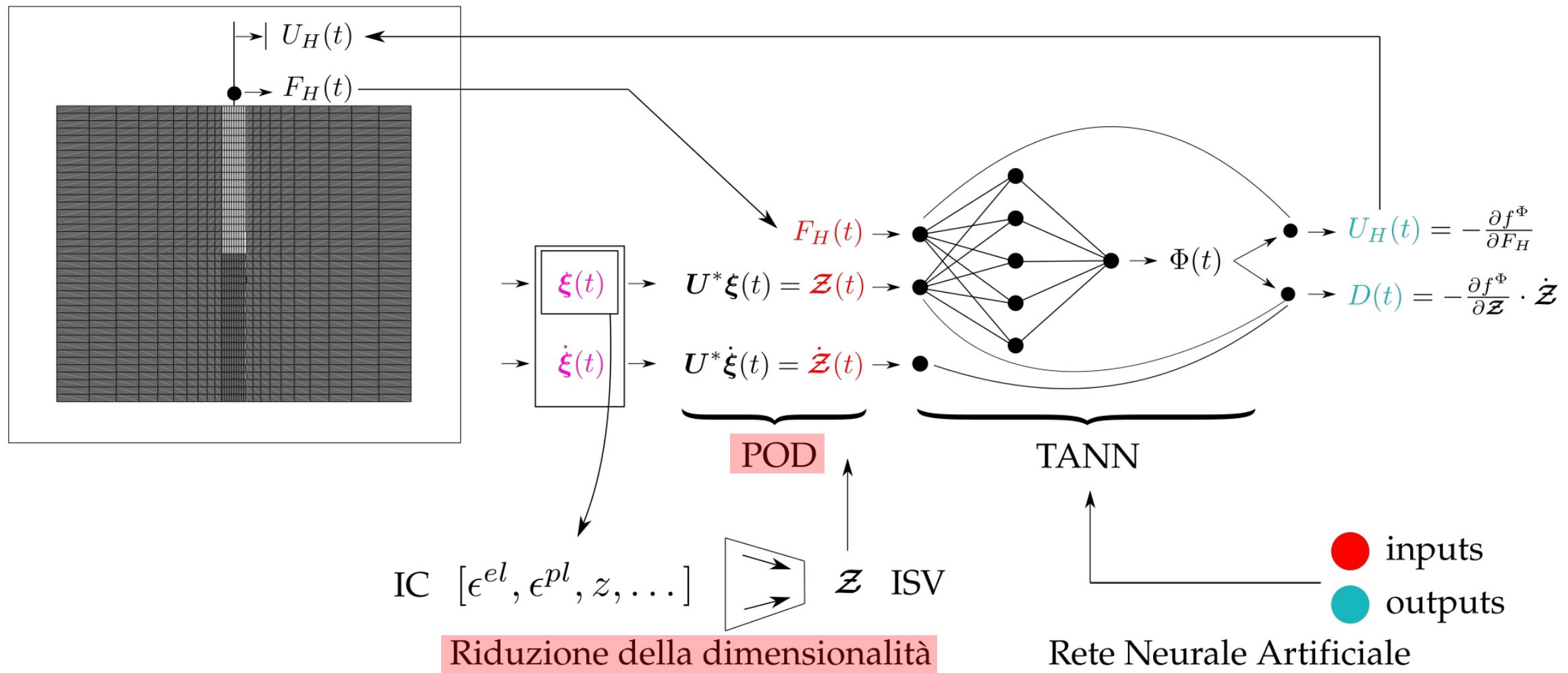
Proper
Orthogonal
Decomposition

(Lumley, 1967)

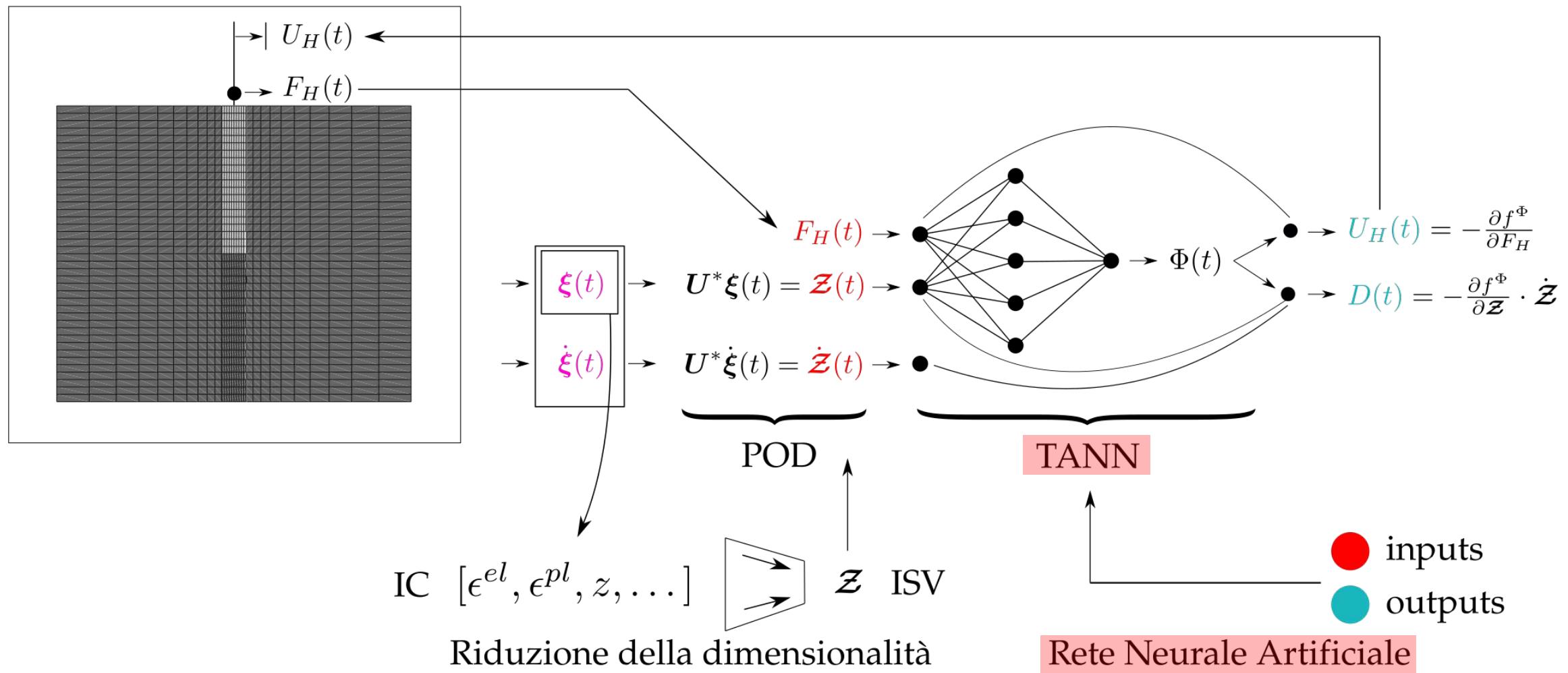
Thermodynamics – based
Artificial
Neural
Network

(Masi et al., 2022)

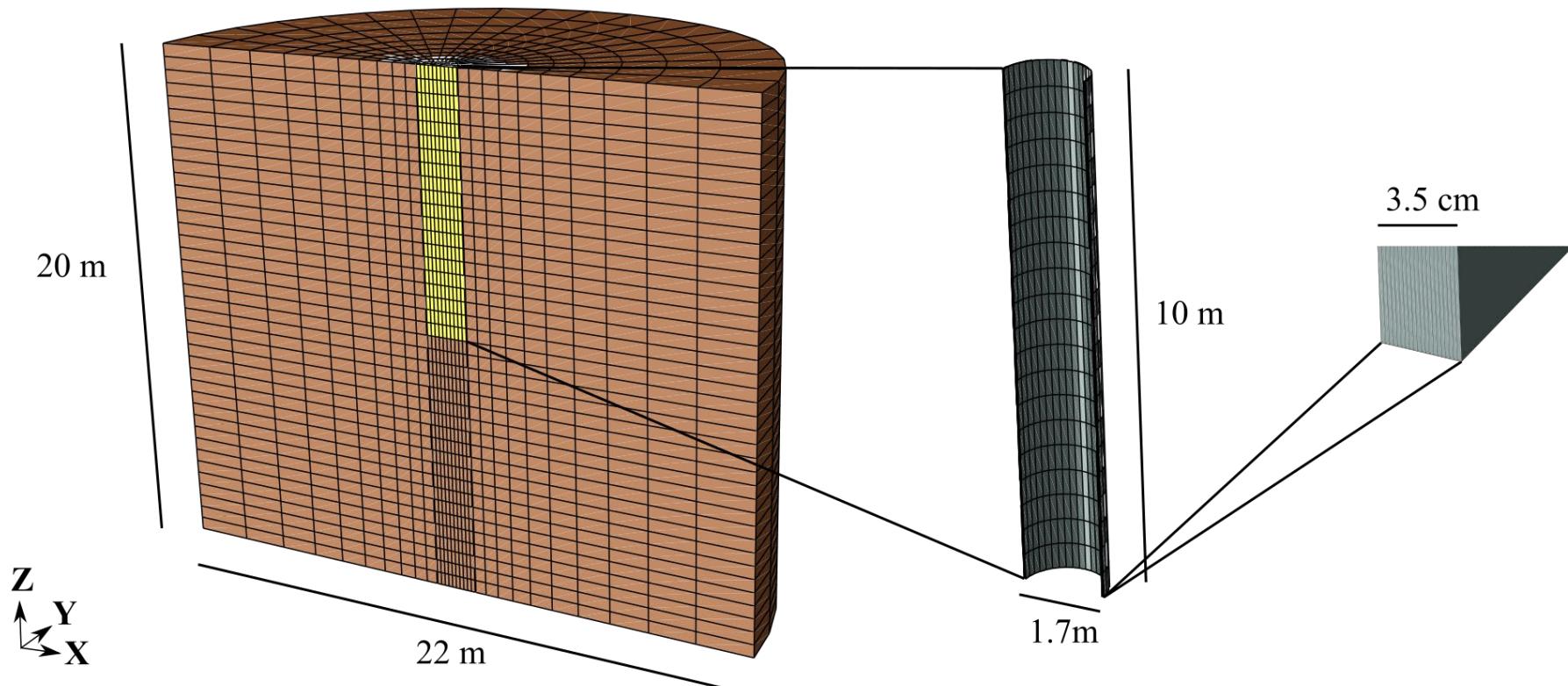
Macroelemento POD - TANN



Macroelemento POD - TANN



Caso Investigato



Argilla

$$\rho_{sat} = 2Mg/m^3$$

$$S_u(z) = 10 + 0.3p'(z)$$

$$E(z) = E_{ref} \left(\frac{p'(z)}{p'_{ref}} \right)^{0.5}$$

$$p'_{ref} = 30kPa$$

$$E_{ref} = 500S_{u,ref}$$

$$S_{u,ref} = 20kPa$$

$$\nu = 0.4$$

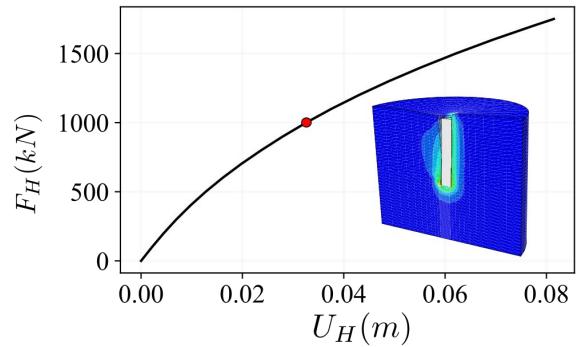
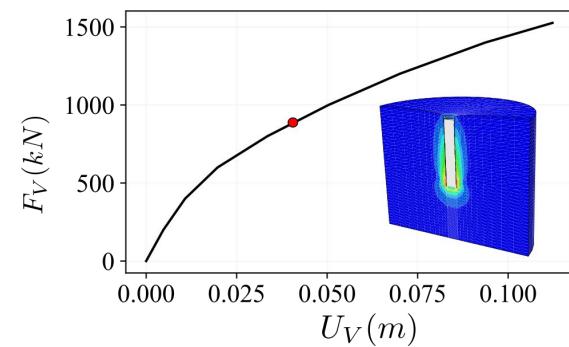
Acciaio

$$\rho_{sat} = 7.85Mg/m^3$$

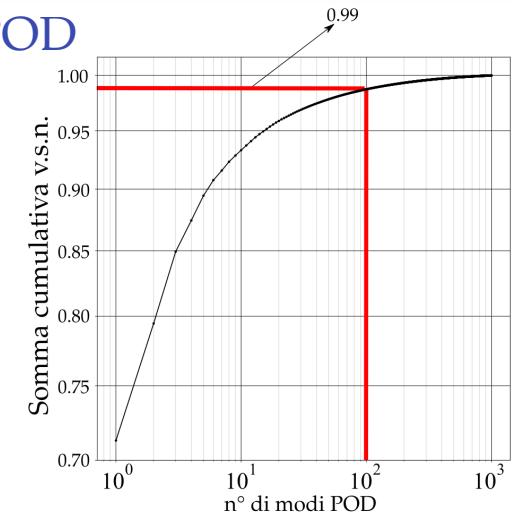
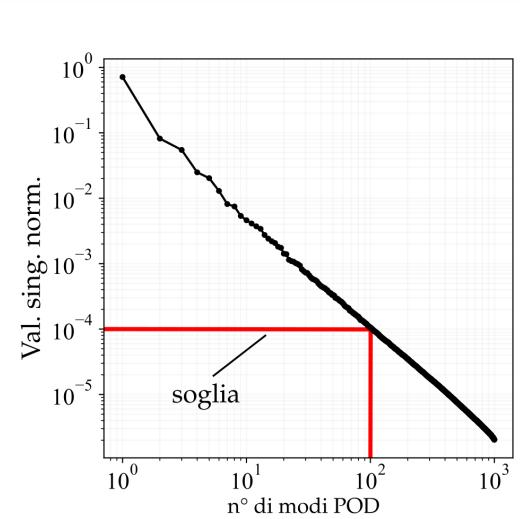
$$E_s = 210GPa$$

$$\nu_s = 0.3$$

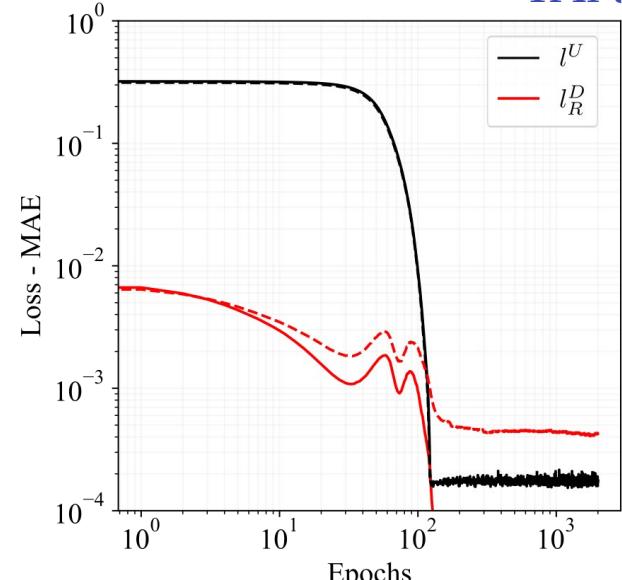
Database



Addestramento



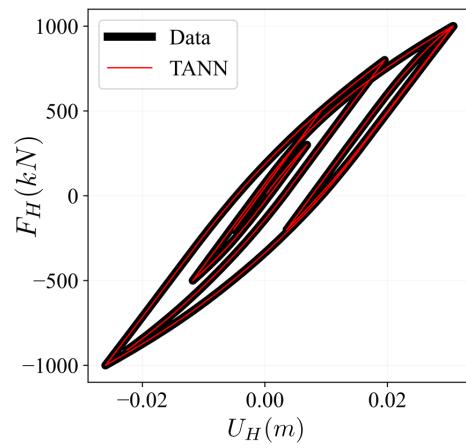
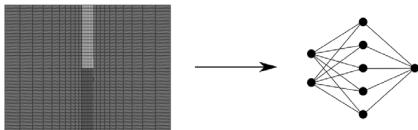
TANN



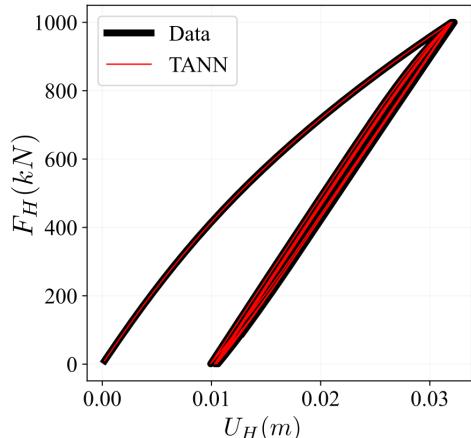
$$\ell^U = \|U_H - \bar{U}_H\|$$

$$\ell^D = \|Relu(-D)\|$$

Riproduzione risposta 1D

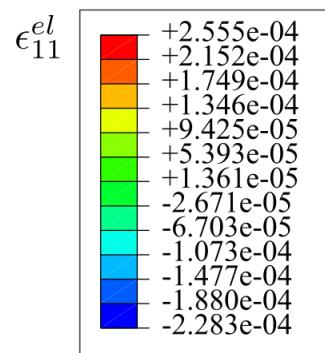
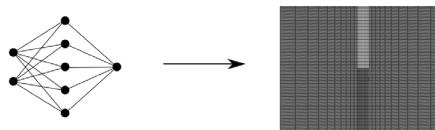


Carico
simmetrico

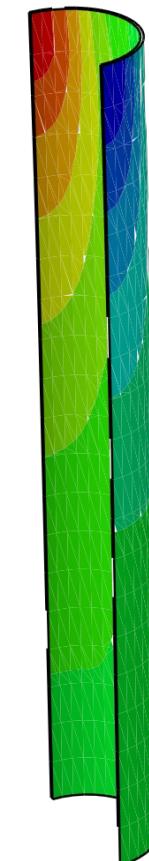


Carico
asimmetrico

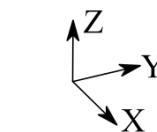
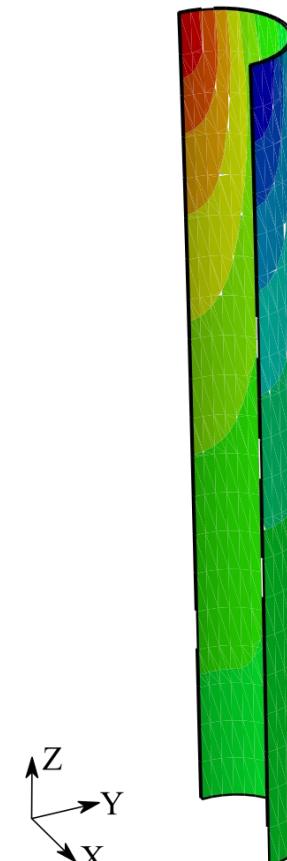
Ricostruzione delle IC



Simulazione



Ricostruzione



Considerazioni finali

PRO

- Risposta monodimensionale termodinamicamente ammissibile (TANN).
- Possibilità di ricostruire la risposta interna al macroelemento data l'esistenza di una funzione inversa (POD).
- Definizione non supervisionata delle variabili di stato interne alla macroscale.
- Velocità di ottenimento della risposta macroscopica a rete addestrata (accuratezza ed efficienza).

CONTRO

- Iniziale impegno computazionale per la generazione del database per l'addestramento.
- Necessità di formulare o imparare dai dati una legge di evoluzione per le variabili interne ottenute tramite POD (possibili approcci *data-driven*: ANN o DMDc)
- Come tutti i metodi *data-driven*, dipendenza dal database utilizzato per l'addestramento (buona capacità di generalizzazione grazie alla formulazione termodinamica)

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Grazie per l'attenzione!

Domande?

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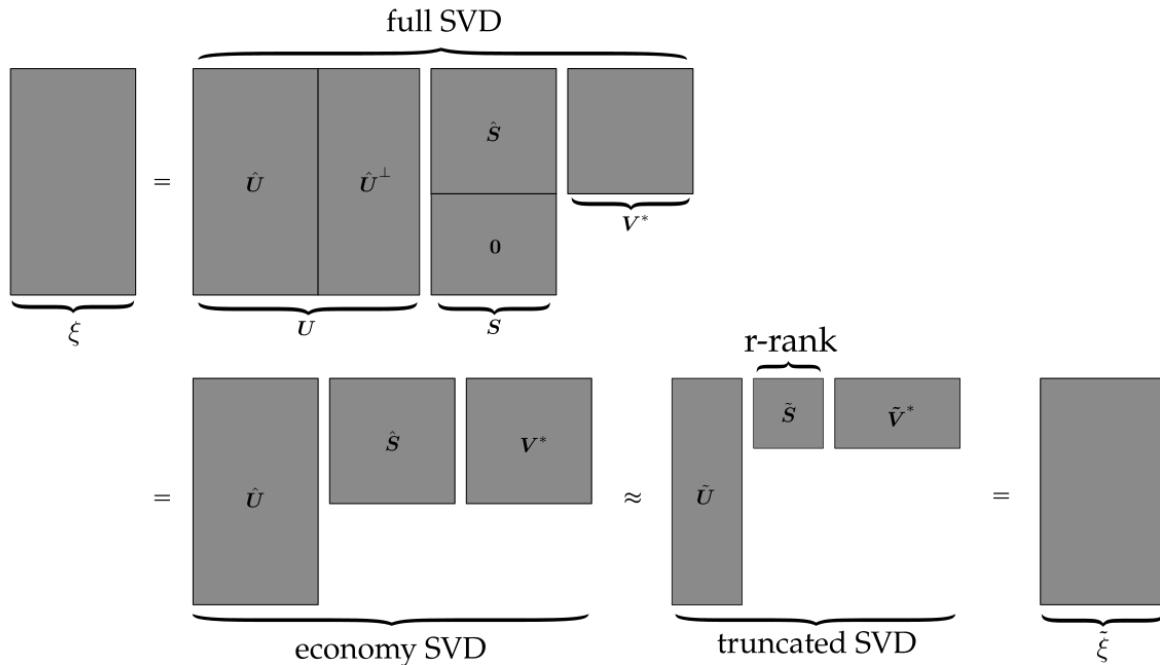
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POD

$$\mathcal{Z} = \mathcal{O}(\xi)$$

$$\xi = USV^* \approx \tilde{U}\tilde{S}\tilde{V}^* \rightarrow Z = \tilde{U}^*\xi$$



ANN

$$p_j^{(h)} = \mathcal{A}^{(h)} \left(r_j^{(h)} \right)$$

$$r_j^{(h)} = \sum_{l=1}^{n_{\mathcal{N}}^{(h-1)}} \left[\left(\textcolor{red}{w}_{jl}^{(\textcolor{red}{h})} p_l^{(h-1)} \right) + b_j^{(\textcolor{blue}{h})} \right]$$

$$\mathcal{L}(\mathcal{I}, H, \bar{\mathcal{O}}_i) = \sum_i (\mathcal{O}_i(\mathcal{I}, H) - \bar{\mathcal{O}}_i)$$

$$H = \{W^{(\textcolor{red}{h})}, b^{(\textcolor{blue}{h})}\}, \forall h \in [1, k]$$

