An investigation on load re-distribution and 1D vs 3D strategies for cyclic degradation of monopiles based on cyclic soil contour diagrams

Majid Goodarzi

mdgi@cowi.com

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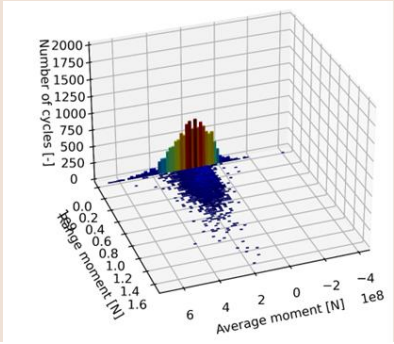
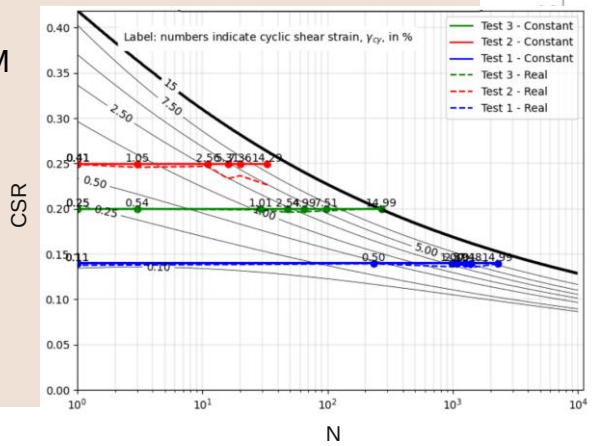
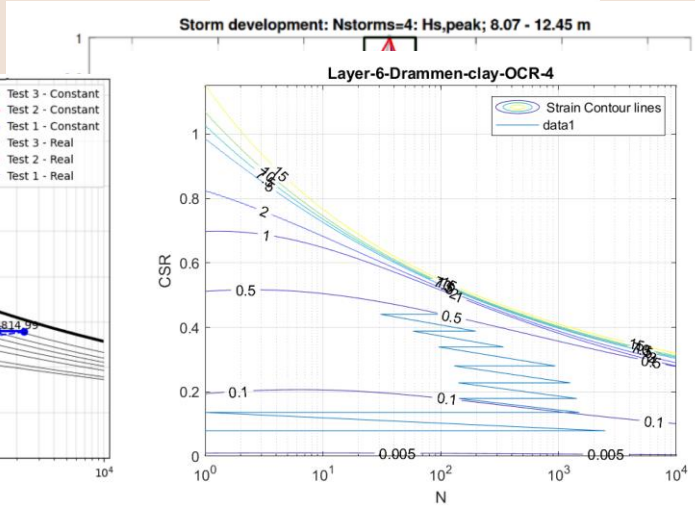
Cyclic degradation Input

- Site Specific storm event
- Integrated Load Analysis
- Markov Matrix of the cyclic load at mudline – Location specific
- Site Specific Soil Data
- Cyclic soil contour diagram
  - Simpler compared to advanced CM
  - Mentioned in DNV standard







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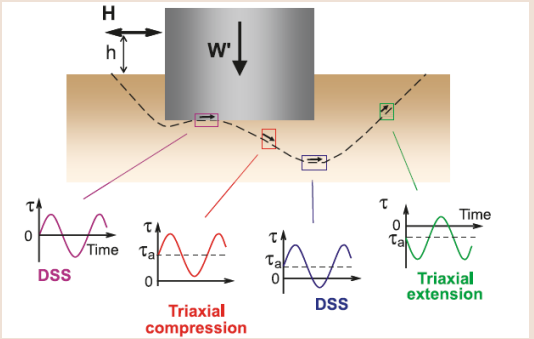
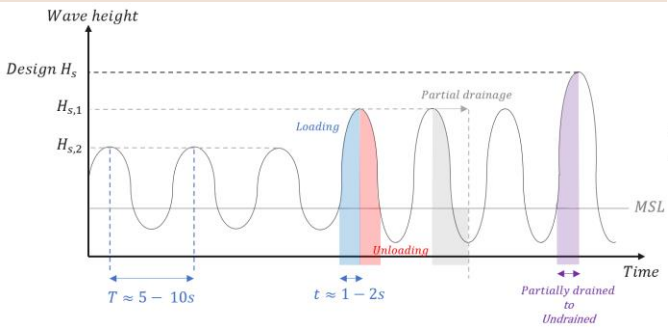
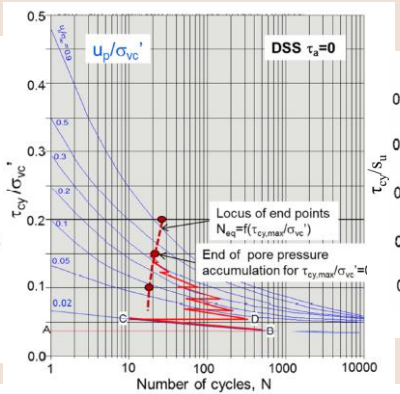
Cyclic degradation based on soil cyclic contour diagrams

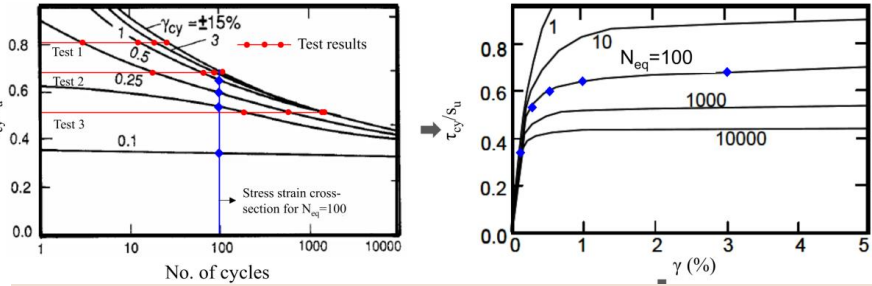
- Mainly developed for gravity-based and suction anchor
- The whole foundation could be assumed to be represented with one point
- The storm loading will be normalized and assumed to be one to one in the contour diagram: “assuming that the shear stresses are proportional to the loads”



(plots from Andersen 2015)







(plots from Zhang et. al., 2017)

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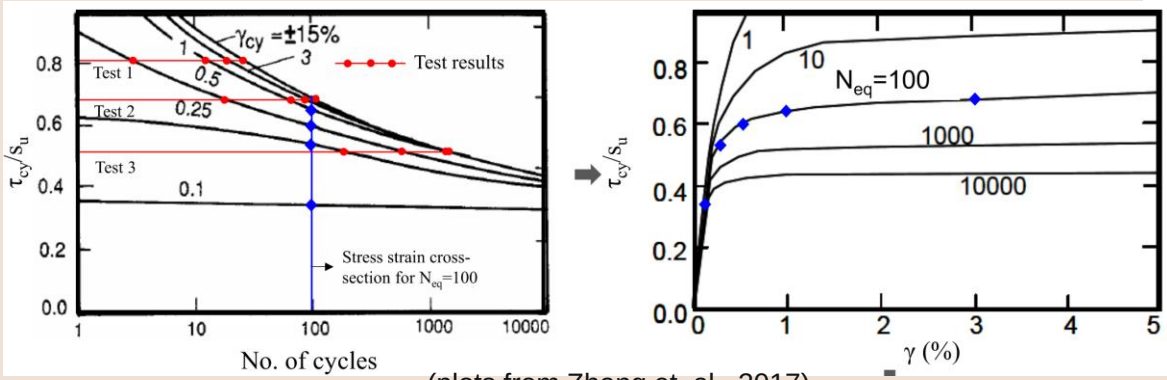
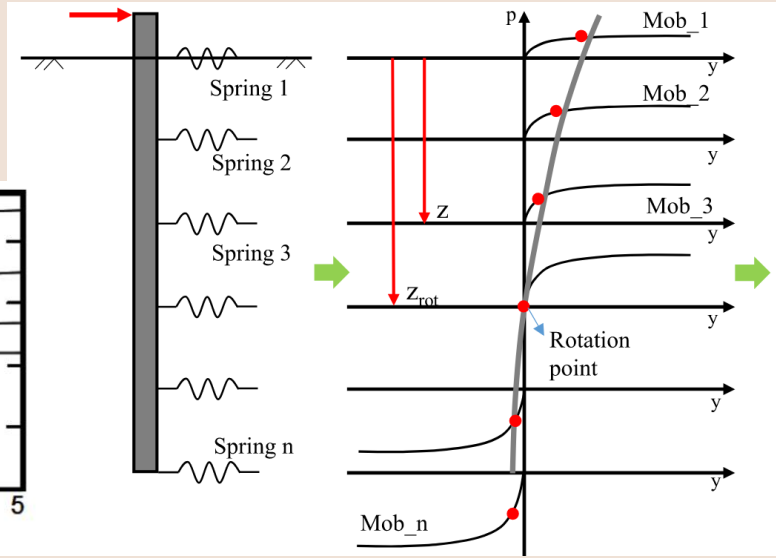
Cyclic degradation for pile foundation

For pile foundation two aspect are critical:

- Conversion of mudline load to CSR at surrounding soil and consequently in cyclic soil contour diagrams
- Redistributing the load across the pile length



(plots from Zhang et. al., 2017)



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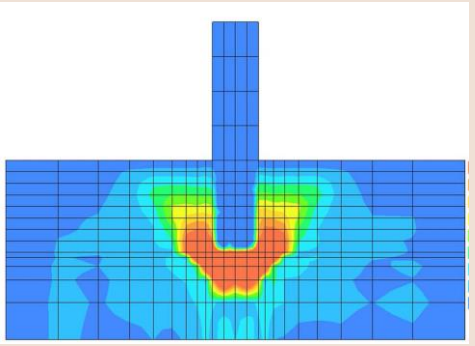
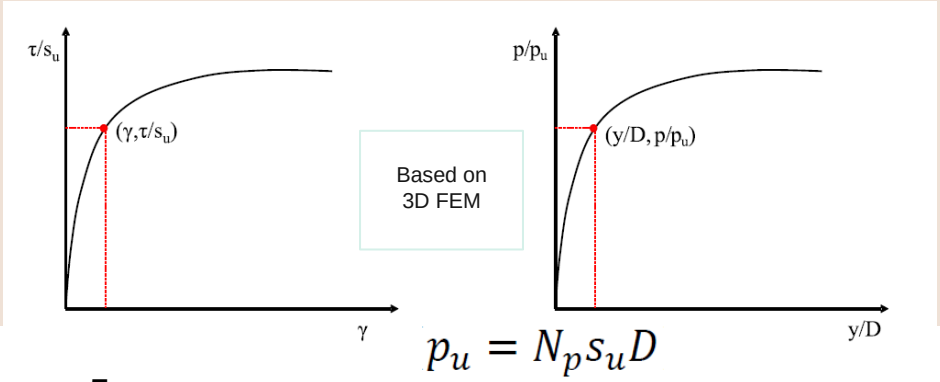
From soil-pile interaction to stress-Strain curve and vice versa

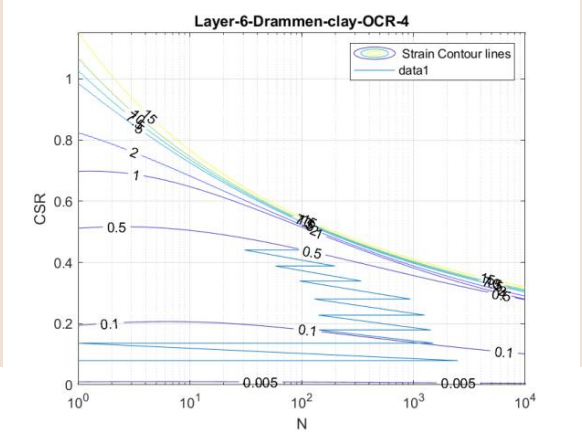
- UDCAM/PDCAM (Neq calculation at each element)
- Simplified UDCAM/PDCAM (Neq calculation at each layer)
  - Analytical solutions (Zhang et al. 2016)
  - 3D FEM (Jostad et. al., 2023; Ragni et al. 2023)



(plot from Jostad et. al., 2023)



$$p_u = N_p s_u D$$



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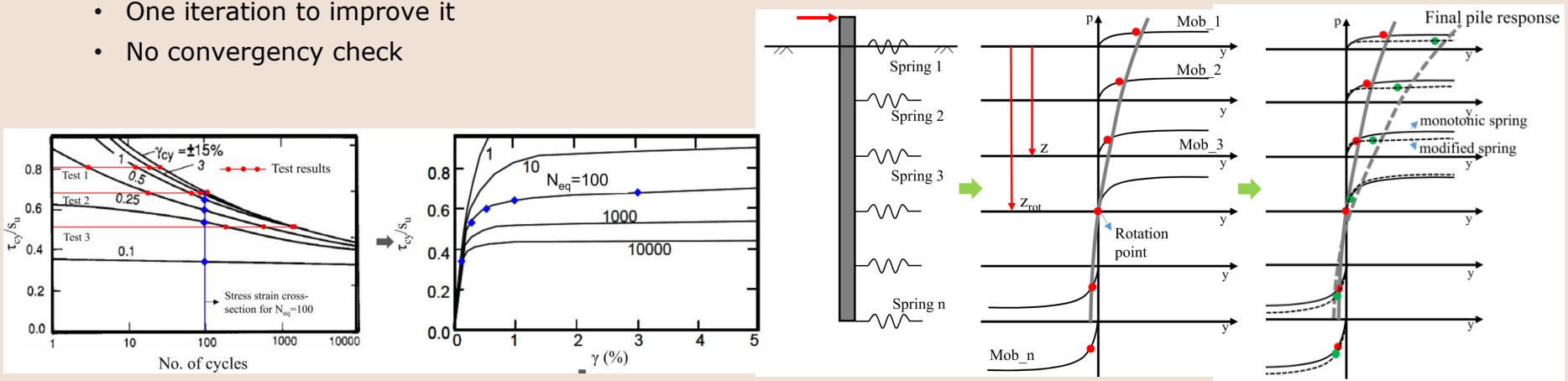
Load redistribution and strain/pore pressure accumulation

- Applying the storm event parcel by parcel in a 1D-beam Winkler model to allow for the redistribution of soil pressures and load-transfer down the pile (Zhang et al 2016).
  - Each step based on previous estimate of N
  - One iteration to improve it
  - No convergency check



(plots from Zhang et. al., 2017)

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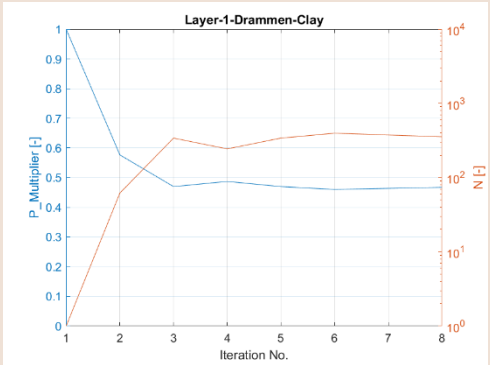
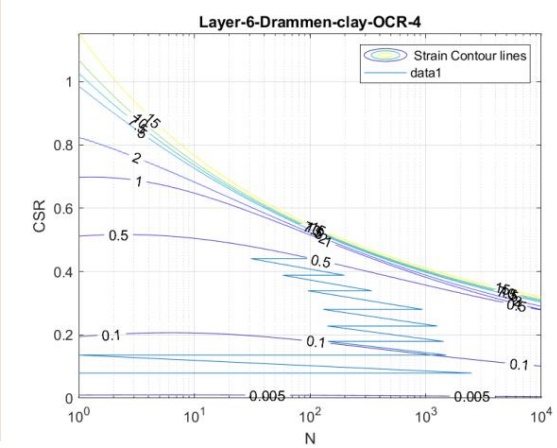
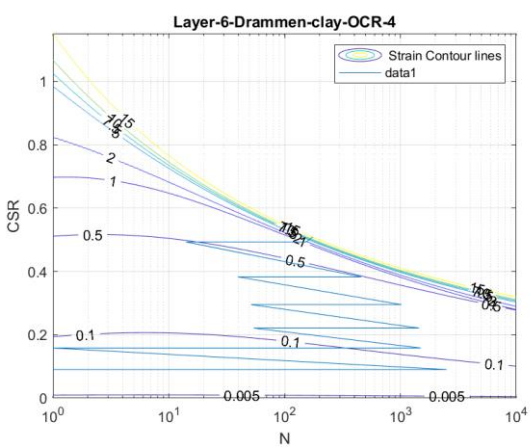
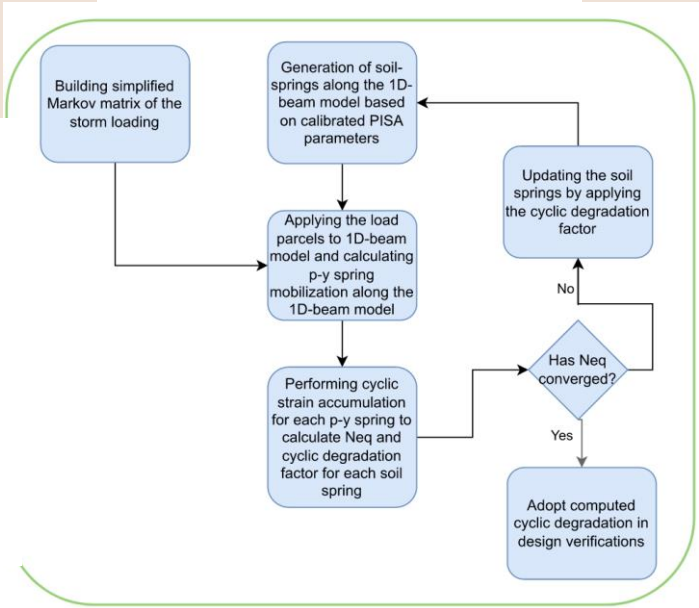
Load redistribution and strain/pore pressure accumulation

- Applying the whole storm at once in several iteration (Jostad et. al., 2023; Ragni et al. 2023)
  - With scaling the CSR to failure
  - Without scaling the CSR to failure





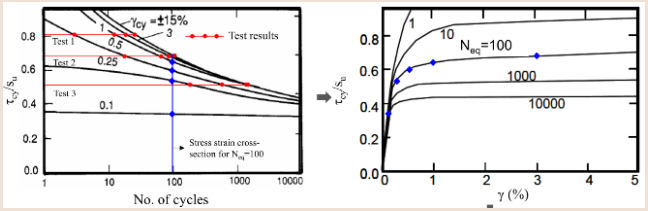


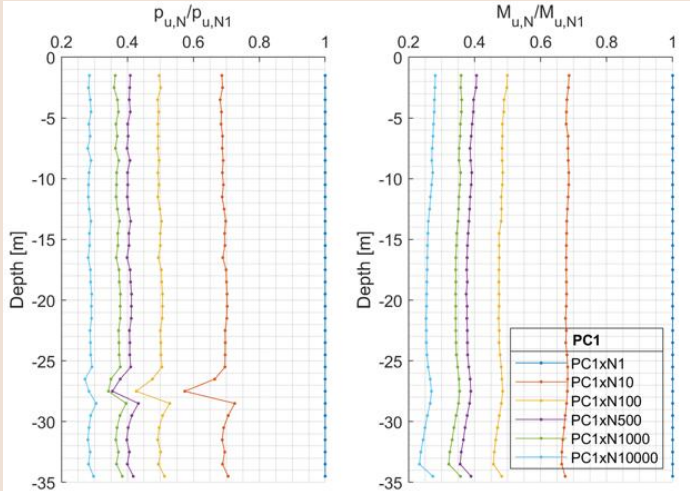


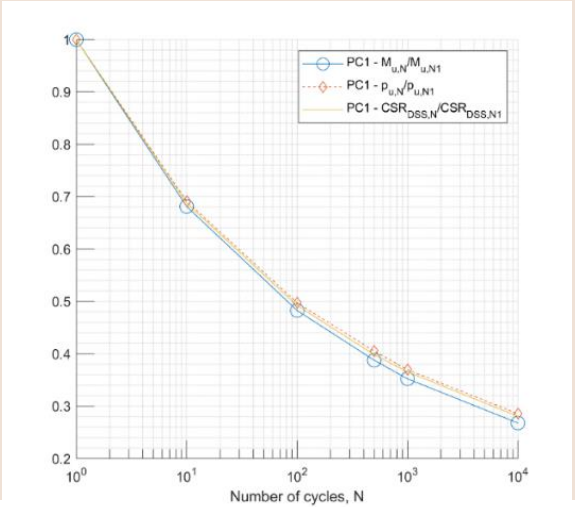
3D FE vs 1D beam models

- Even the Simplified UDCAM in 3D can be time-consuming for industry practice due to iterations needed for redistribution and number of load parcels
- Is it possible to combined the 3D FE and 1D beam models ?
- We can calibrate Np factor, and it is independent from Su

$$p_u = N_p s_u D$$







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3D FE vs 1D beam models

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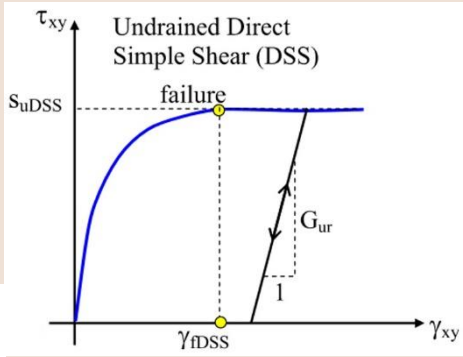
- Is it possible to combined the 3D FE and 1D beam models ?
- We can calibrate Np factor, and it is independent from Su
- In general, in two-way cyclic contour diagrams, the stress-strain curves can be calibrated with one value of strain to failure using NGI-ADP model

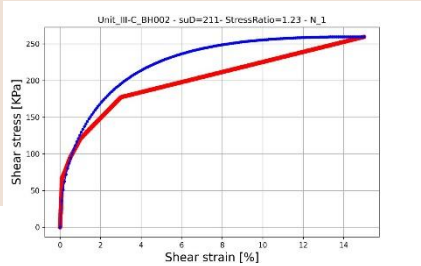


(Table from Jostad et. al., 2023)

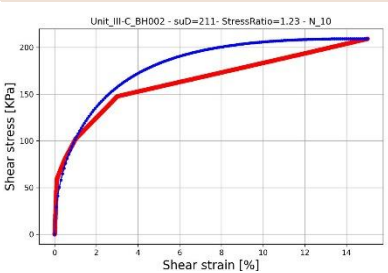
Table 3. Stress–strain curve fitting parameters

$(G_0/p_0')^*$	$(\gamma_{psf})^{*a}$ (%)	$(\tau_0/p_0')^{*a}$	$(\tau_{cy}/p_0')_{max}$ $N=1$	$(\tau_{cy}/p_0')_{max}$ $N=3$	$(\tau_{cy}/p_0')_{max}$ $N=10$	$(\tau_{cy}/p_0')_{max}$ $N=30$
500	21	0	4.4	3.6	2.2	1.5

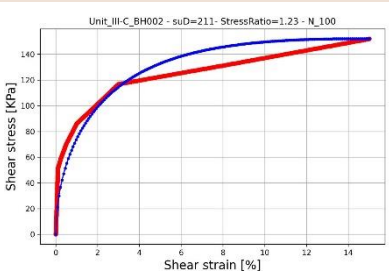
[a]The values are the same across $N = 1, 3, 10, 30$.



Neq=1



Neq=10



Neq=100

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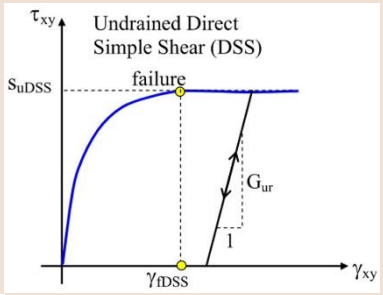
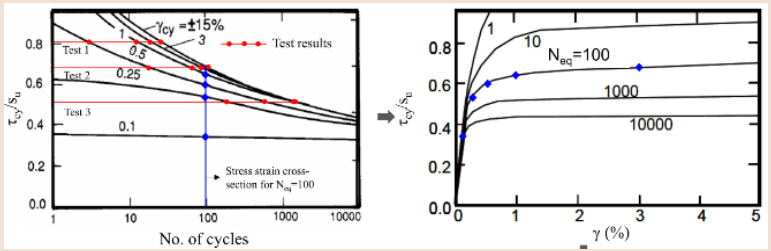
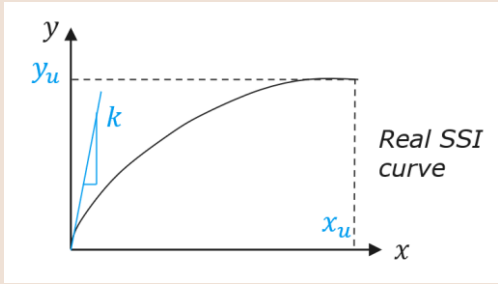
3D FE vs 1D beam models

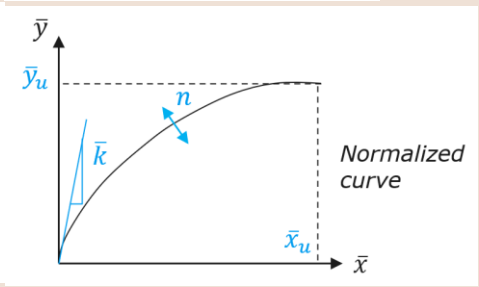
- Even the Simplified UDCAM in 3D can be time-consuming for industry practice due to iterations needed for redistribution and number of load parcels
- Is it possible to combined the 3D FE and 1D beam models ?
- We can calibrate Np factor, and it is independent from Su
- In general, in two-way cyclic contour diagrams, the stress-strain curves can be calibrated with one value of strain to failure using NGI-ADP model
- Can be translated to PISA springs using Su reduction or P-multiplier





(plots from Zhang et. al., 2017)





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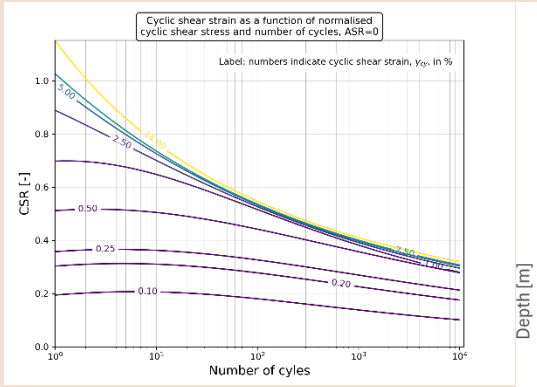
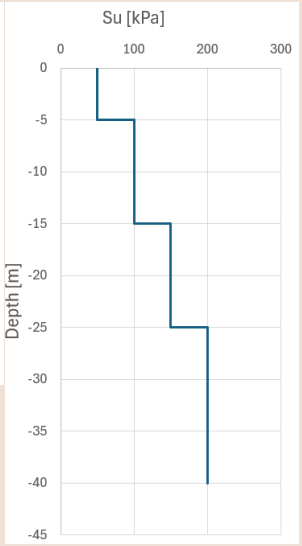
3D FE vs 1D beam models

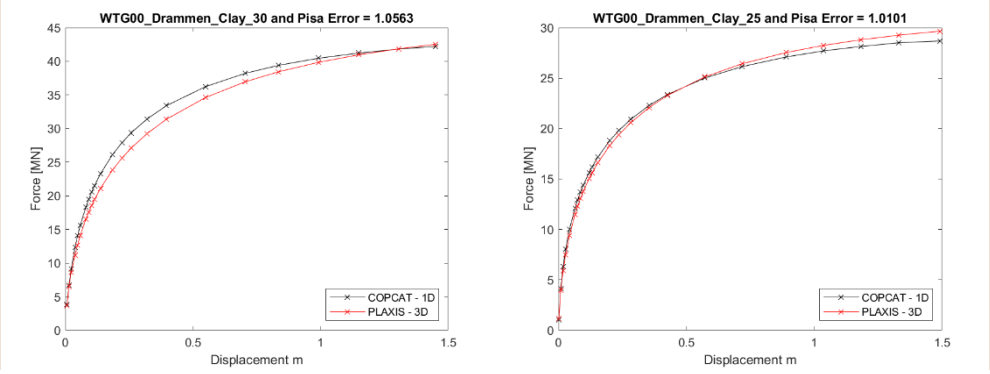
- 3D FE model calibrated at Neq=1 Drammen Clay OCR=4
- Pile diameter = 9.5 m
- Selected peak load:

  H=20 MN with 35 m of lever arm
- 1D PISA framework model calibrated on two pile lengths 25 and 30 m





N	F/Fmax
2500	0.3
1500	0.45
1000	0.55
500	0.65
250	0.75
100	0.85
20	0.925
1	1



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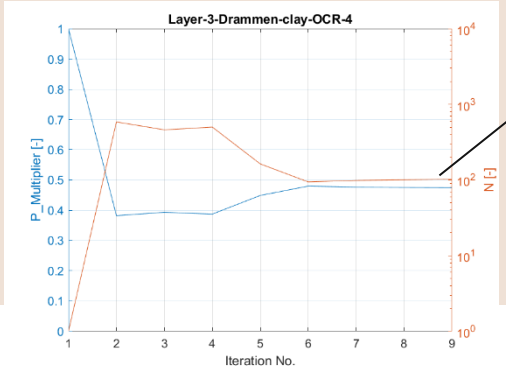
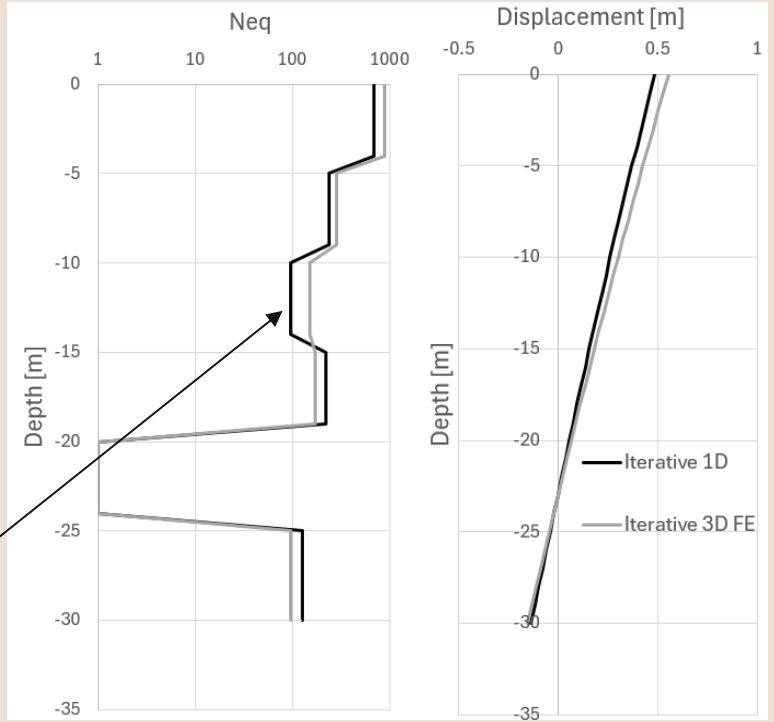
3D FE vs 1D beam models

- 3D FE and 1D beam model were run
- can approximately produce the same results with only Su (P_bar) multiplier
- Convergency can be easily achieved in simple model but not in more layered models
- The proposed method can be done with different variabilities
  - Several 3D FE run with Neq=1, 10, 100
  - PISA parameters (normalized displacement and *n*) as a function of N





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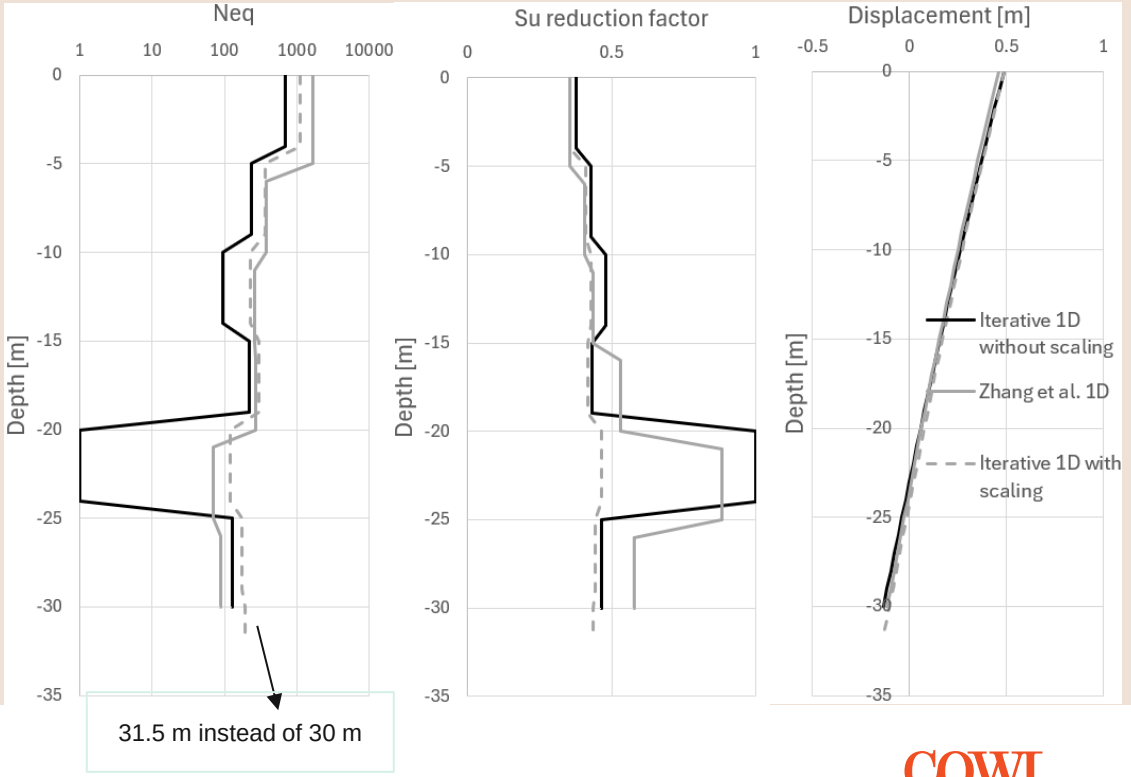
Different load redistribution methods

- Applying the storm event parcel by parcel (Zhang et al 2016)
- Applying the whole storm at once in several iteration (Jostad et. al., 2023; Ragni et al. 2023)
  - Without scaling the CSR to failure
  - With scaling the CSR to failure



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Summary and conclusion

- Simplified UDCAM/PDCAM is still relatively time-consuming for industry practice
- Conic function of PISA framework with 1D beam mode can be good solution by calibrating the PISA normalized parameters as a function of N.
- With a use of contour diagram for 2-way cyclic loading a simple Su reduction factor on PISA springs based on maximum CSR at each N is enough.
- Stress redistributions methods available in the literatures were compared:
  - Parcel by parcel approach with no convergency check is fast but could have some noises in complex models
  - Full storm with iterative solver is more robust but can increase the run-time
  - Scaling the load for each layer would lead to a conservative design in our simple example at least 1.5 m longer pile