Automated Optimisation of Suction Caisson Foundations using a Computationally Efficient Elastoplastic Winkler Model

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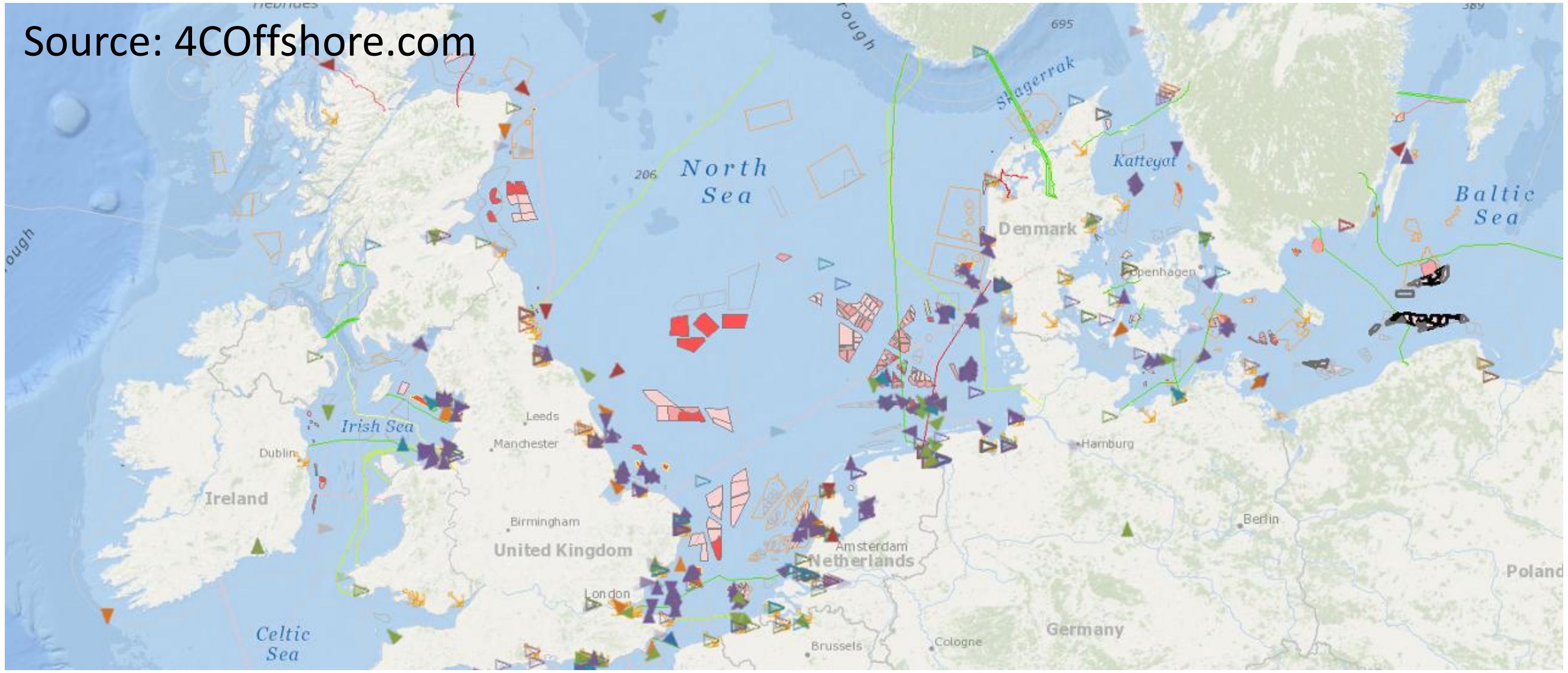
Offshore Wind – Coastal Structures



Source: 4COffshore.com


Source: aprambi.com


Source: Andrew Curtis, Wiki

Structural Options

Ørsted

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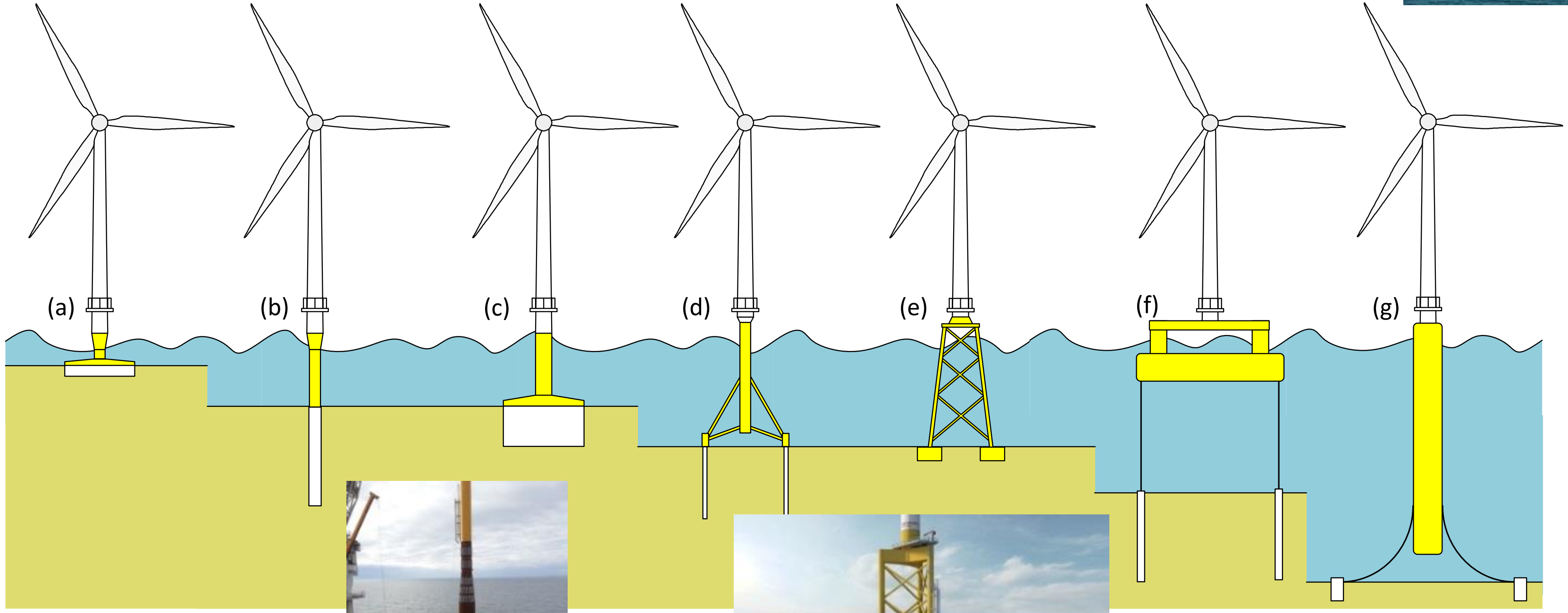
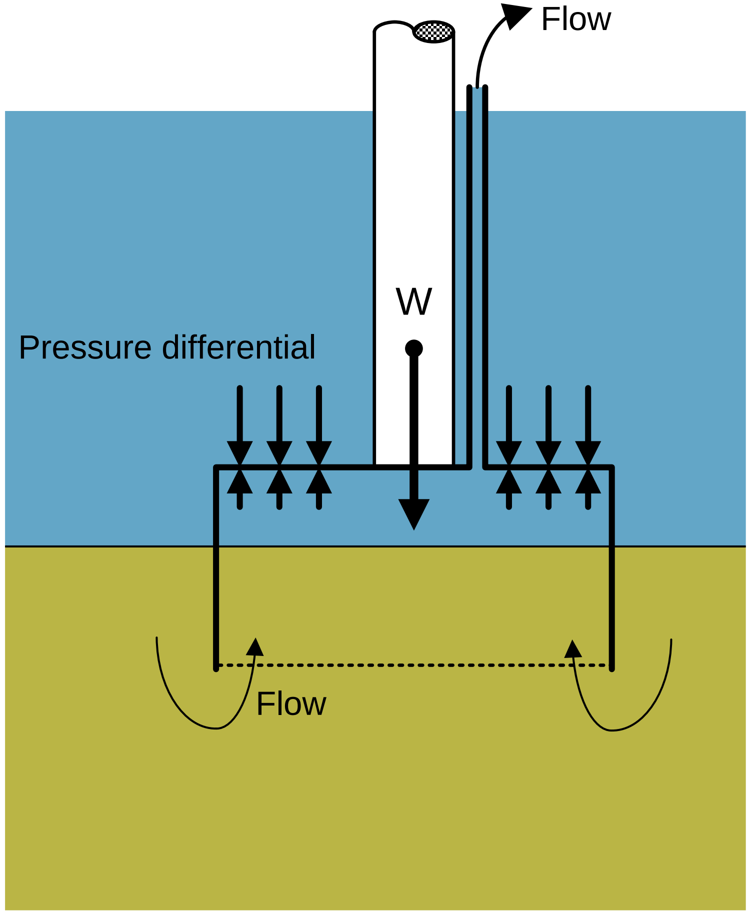


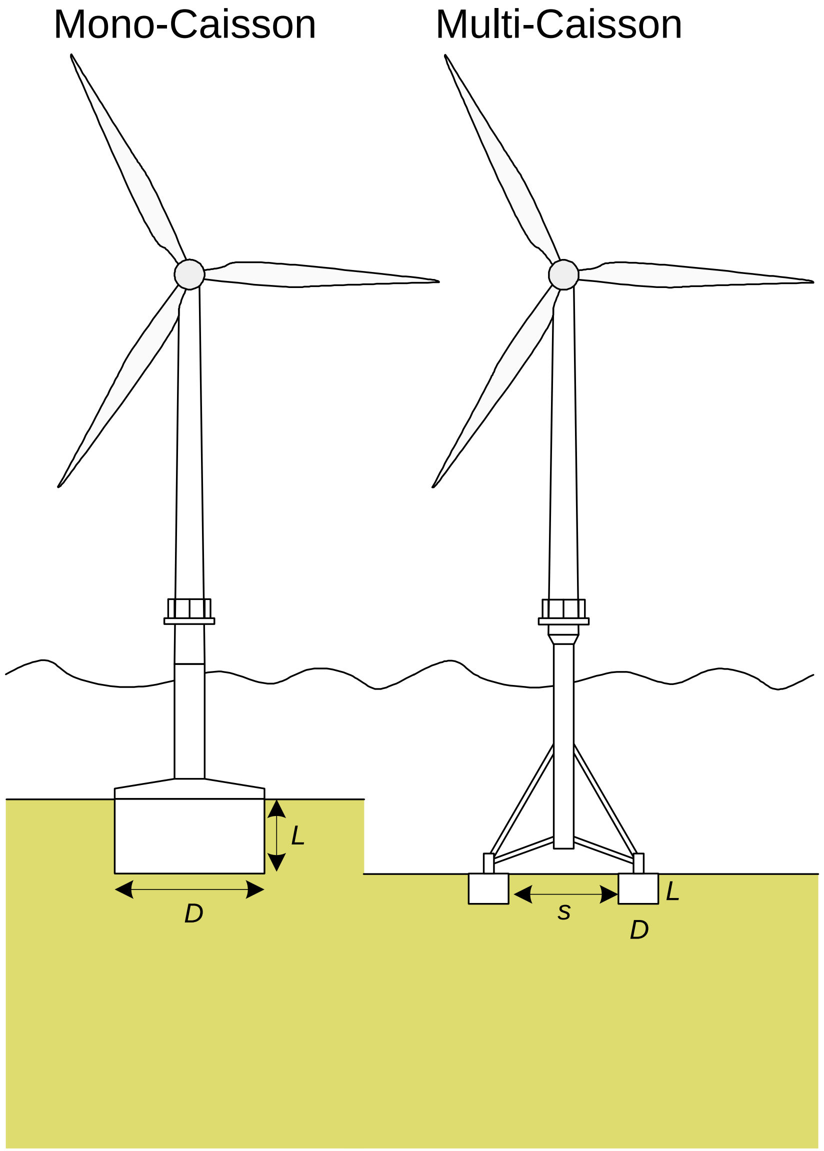
Images from various websites

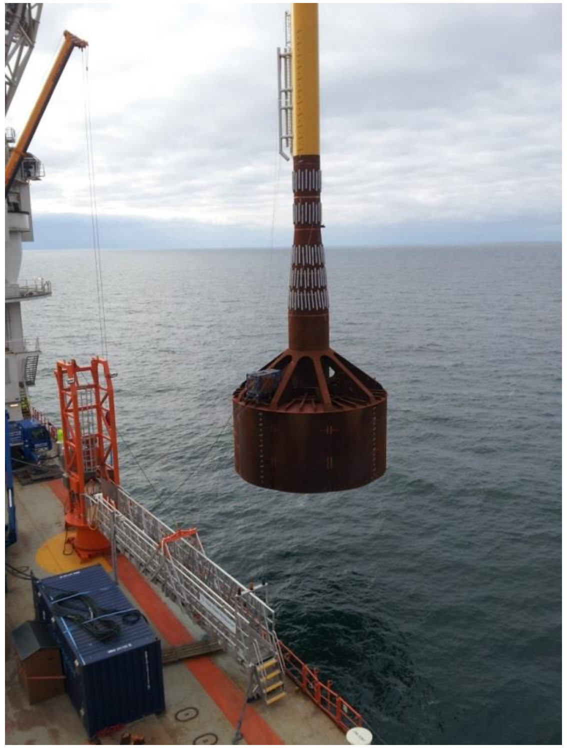
Suction Installation



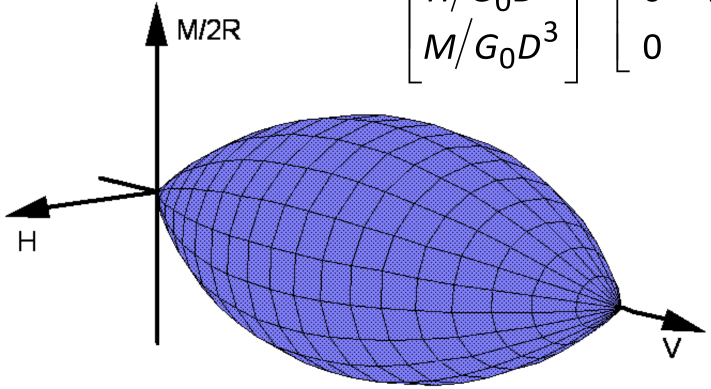
Source: Houlsby, G.T., Ibsen, L.B. and Byrne, B.W (2005) "Suction caissons for wind turbines", Invited Theme Lecture, Proc. International Symposium on Frontiers in Offshore Geotechnics, Perth, Australia, 19-21 September, Taylor and Francis, pp 75-94, ISBN 0415 39063 X

Suction Installed Caissons



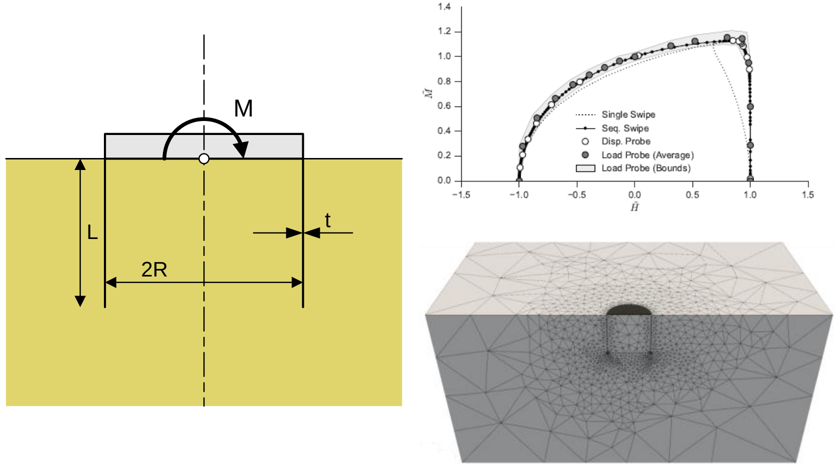


$$\begin{bmatrix} V/G_0D^2 \\ H/G_0D^2 \\ M/G_0D^3 \end{bmatrix} = \begin{bmatrix} K_v & 0 & 0 \\ 0 & K_H & K_C \\ 0 & K_C & K_M \end{bmatrix} \begin{bmatrix} v/D \\ u/D \\ \theta \end{bmatrix}$$



Oxford Research

Laboratory Model Tests

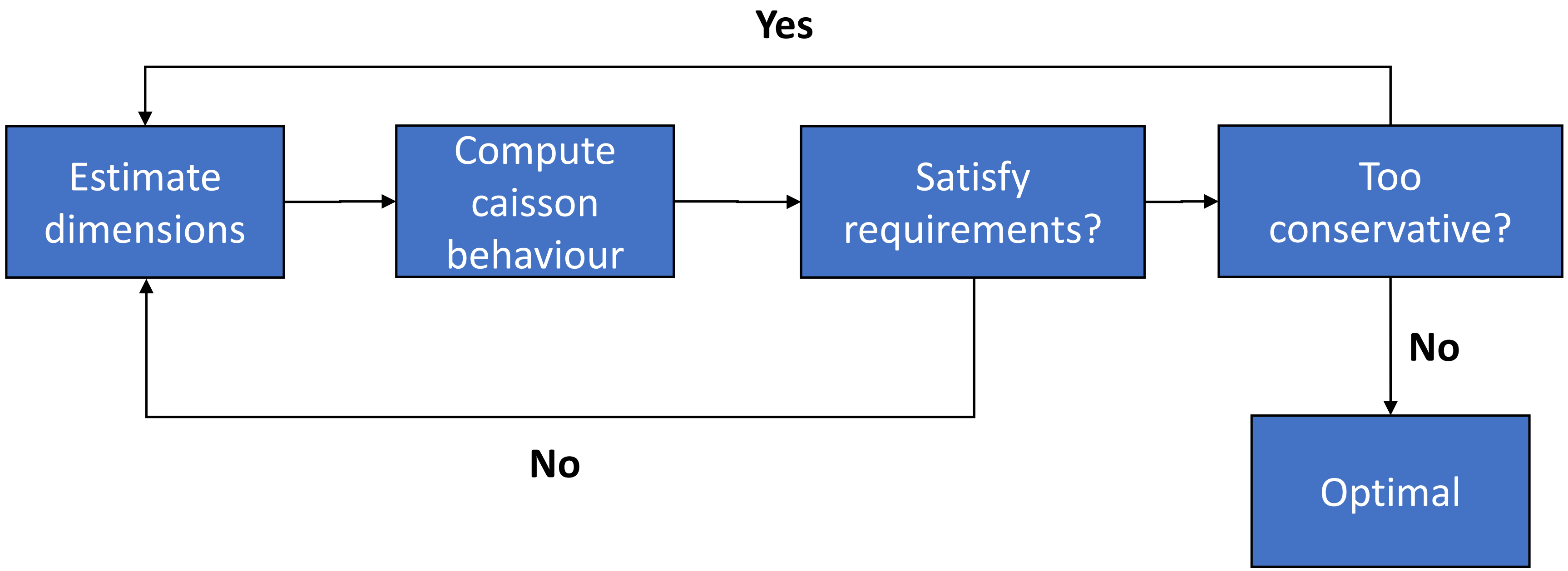


Theoretical and Numerical Analyses

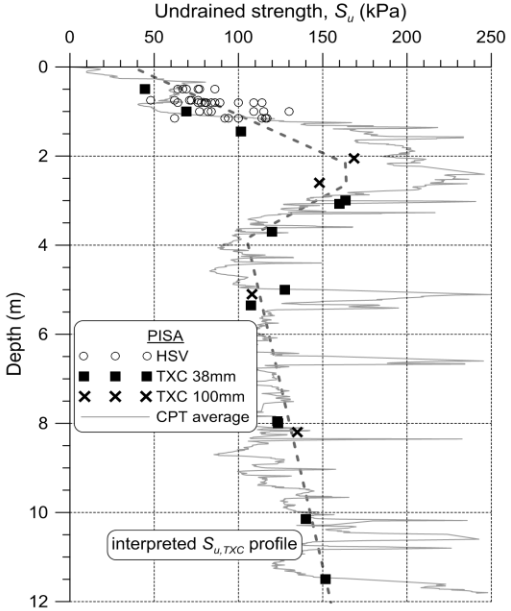
Field Trials

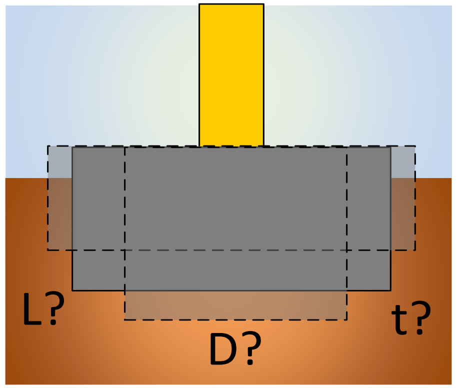
Typical Design Approach

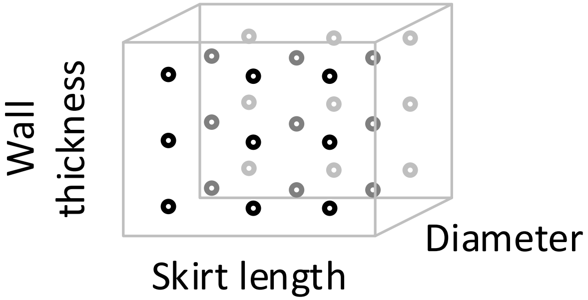
- Limit States (ULS, SLS)
- Weight / Cost
- Installation



Industrialised Design







Automated Design Approach

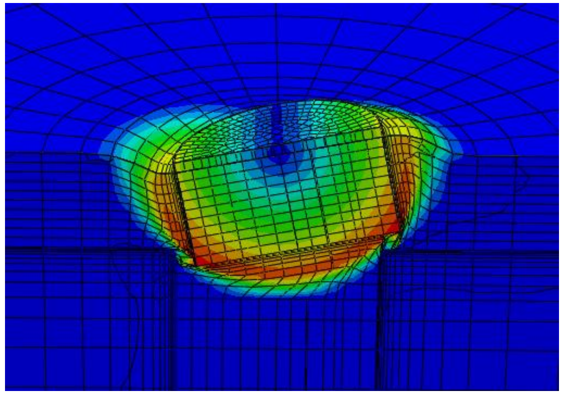
- Cast as a constrained optimisation problem

minimise	Volume of Caisson
subject to	SLS requirements
	ULS requirements
	Installation requirements

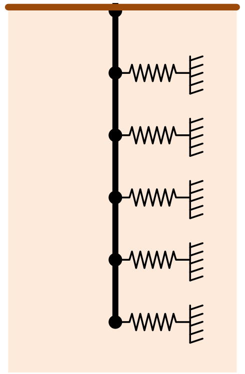
- Iterative → requires fast caisson design method

OxCaisson

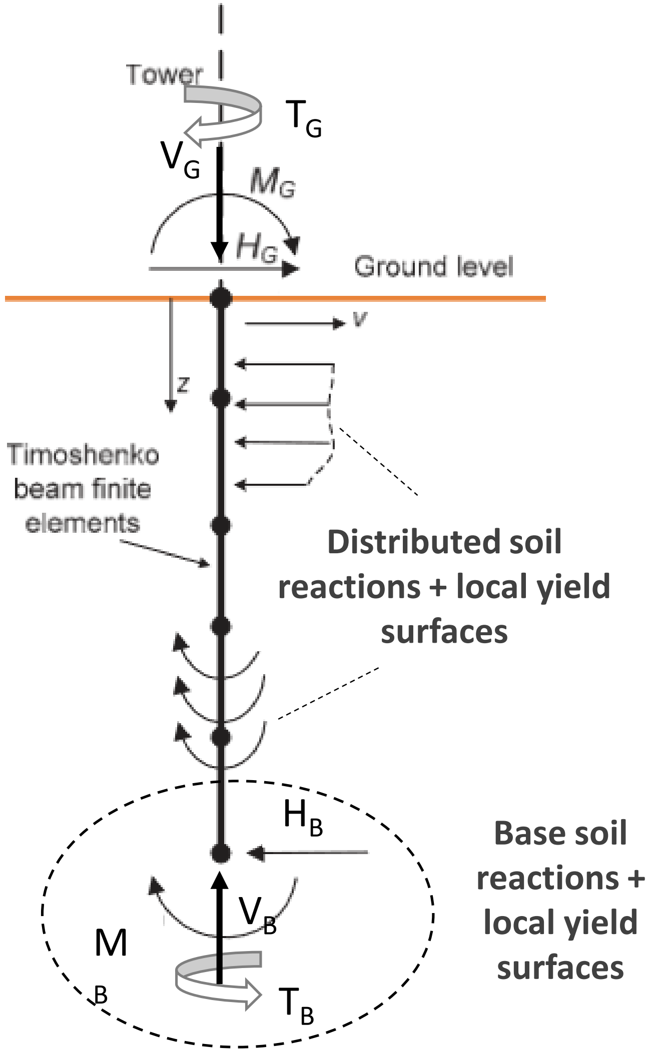
Elastoplastic Winkler model that can efficiently approximate the 3D finite element (3DFE) predictions of suction caisson behaviour in von Mises soil for any 6DoF loading conditions



Accuracy of 3DFE



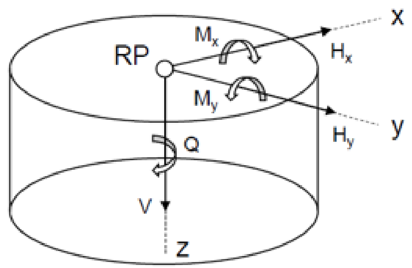
Efficiency of Winkler

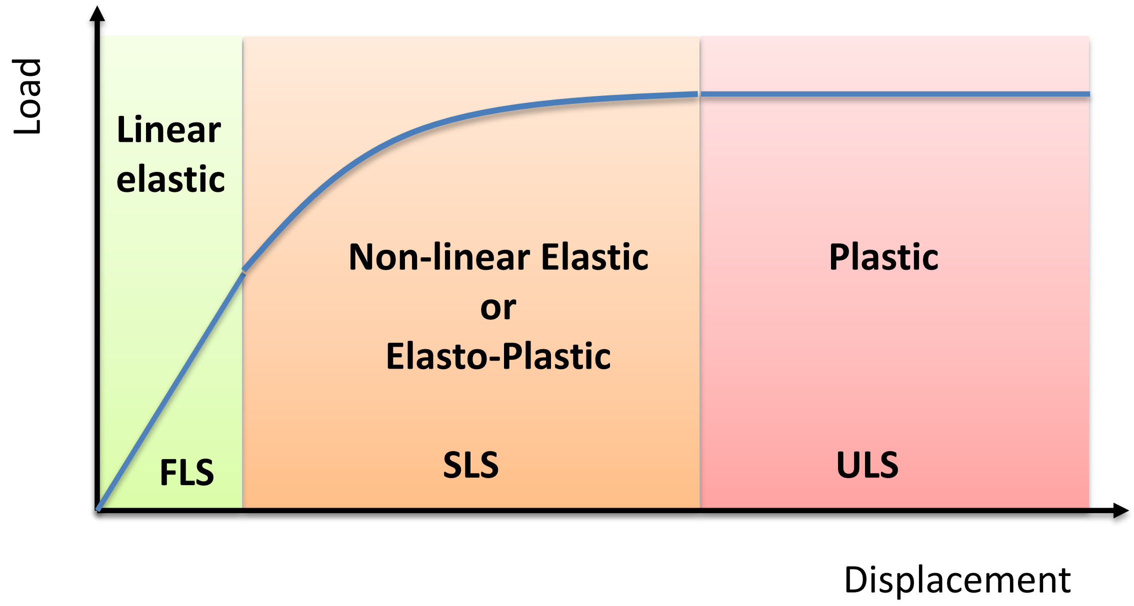


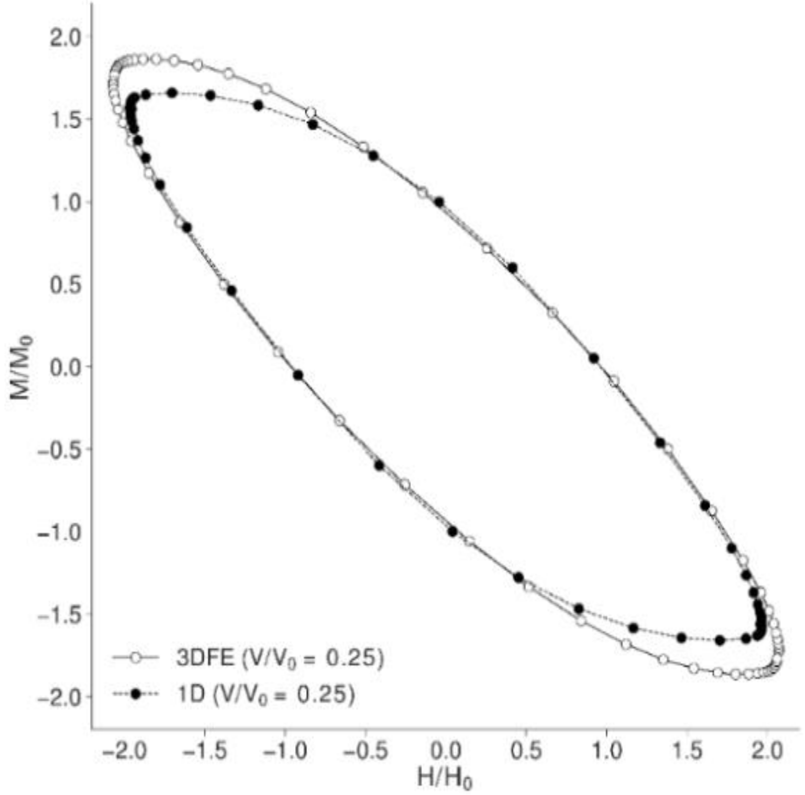
OxCaisson

Suction Caisson Design

- Full 6DoF loading
- OxCaisson: Family of fast design methods calibrated by 3D FE
  - – FLS analysis in linear elastic soil
  - – SLS analysis in non-linear elastic soil
  - – ULS analysis in elasto-plastic soil



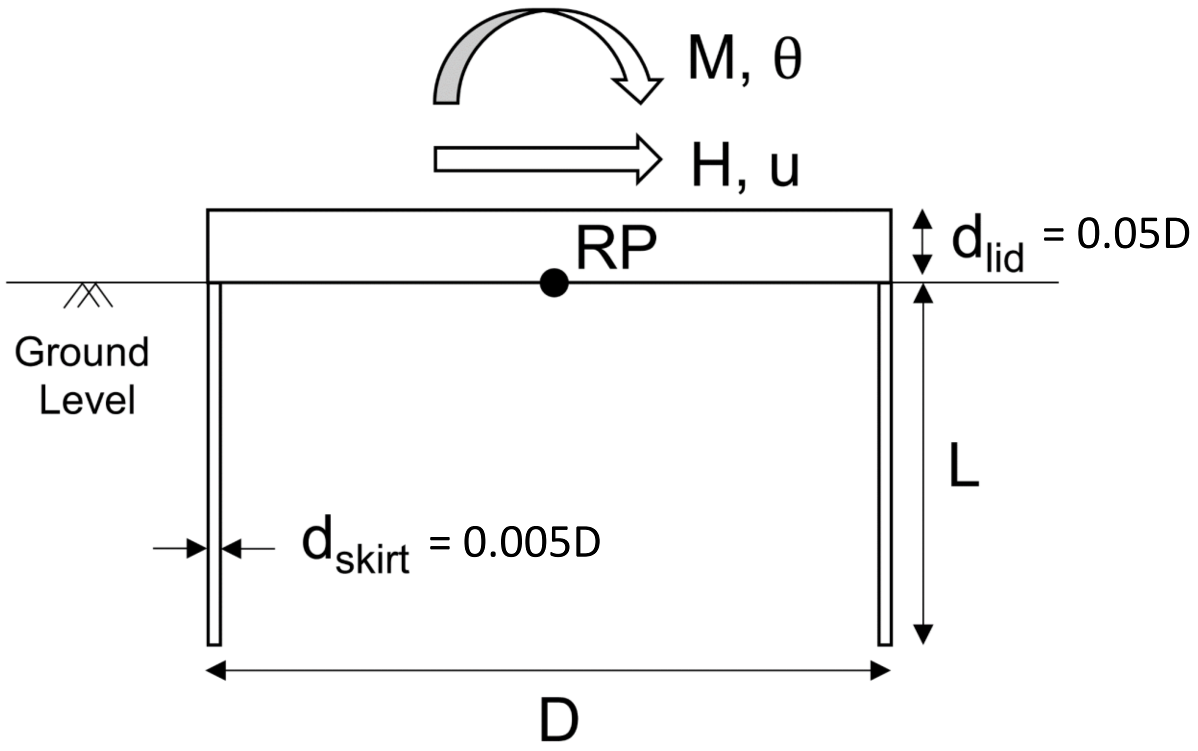




Case Study

Design suction caisson foundation for wind turbine in offshore wind farm

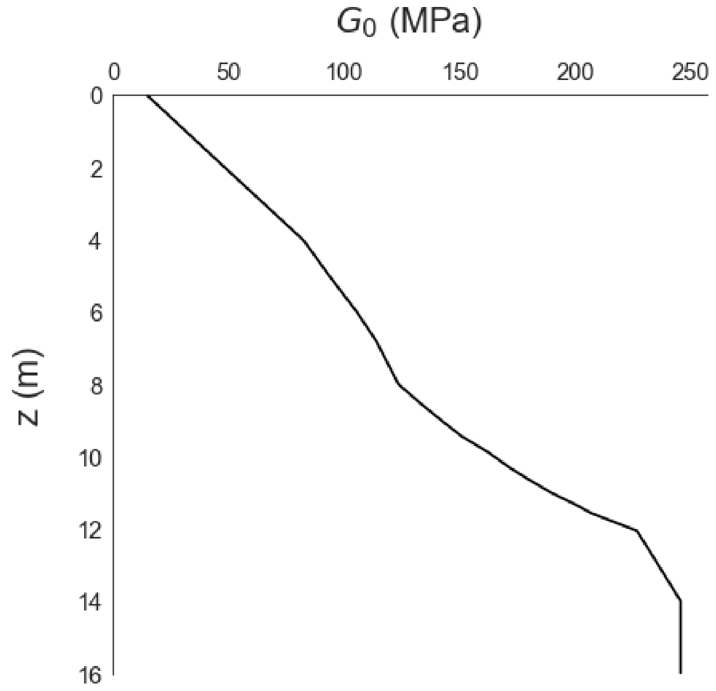
Objective: find the optimal values of skirt length L and diameter D

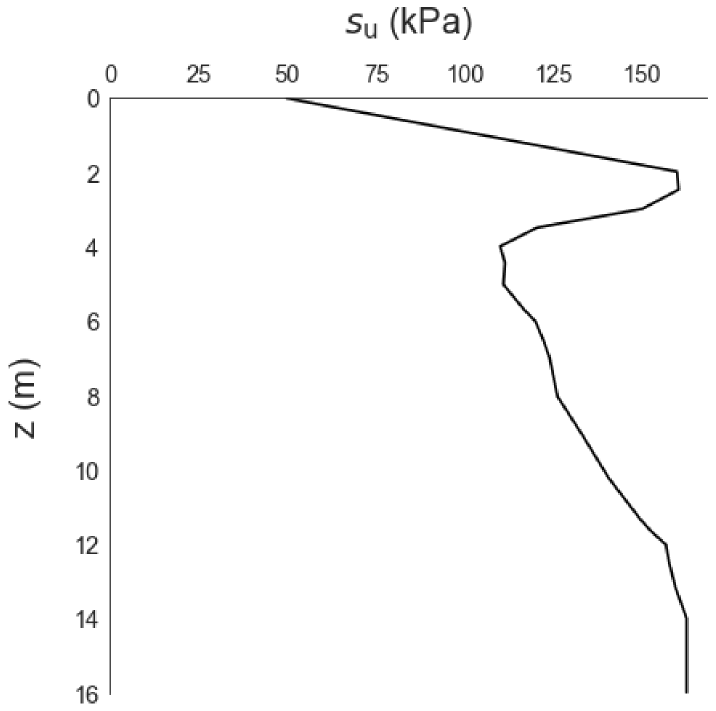


Case Study Assumptions

- Water depth = 25m
- Cowden clay profile (PISA Project)

Factored design loads	SLS	ULS
Max. lateral load at RP	5.33 MN	7.2 MN
Max. bending moment at RP	219 MNm	295.65 MNm

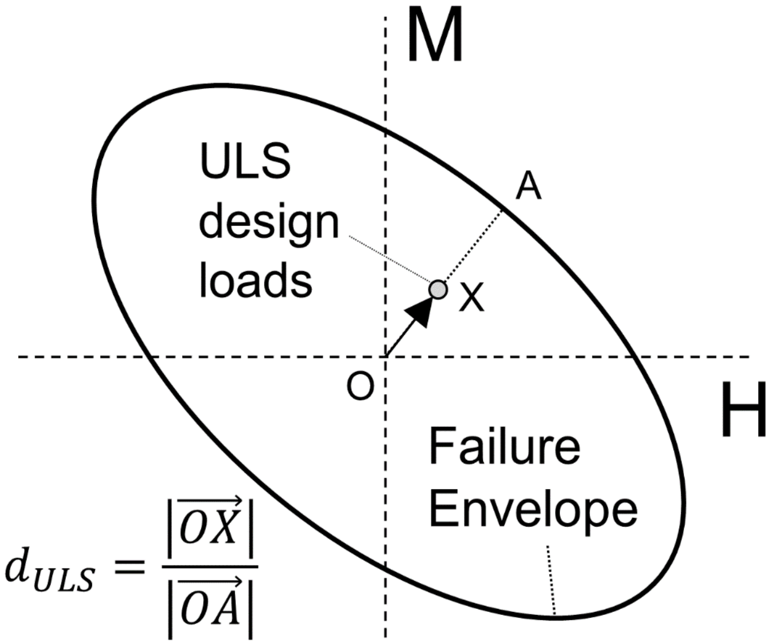




Optimisation Approach

Volume of caisson

minimise	$\pi D^3(0.004975\ L/D + 0.0125)$
subject to	$\theta_M \leq 0.5°$
	$d_{\mathrm{ULS}} \leq 1$
	$p_{\mathrm{suction}} \leq 350\mathrm{kPa}$

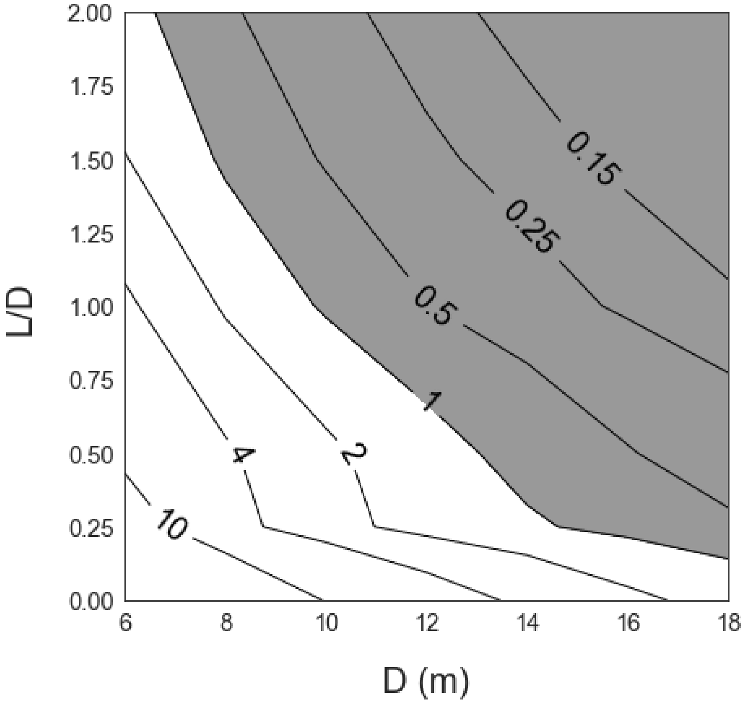


$$d_{ULS} = \frac{|\overrightarrow{OX}|}{|\overrightarrow{OA}|}$$

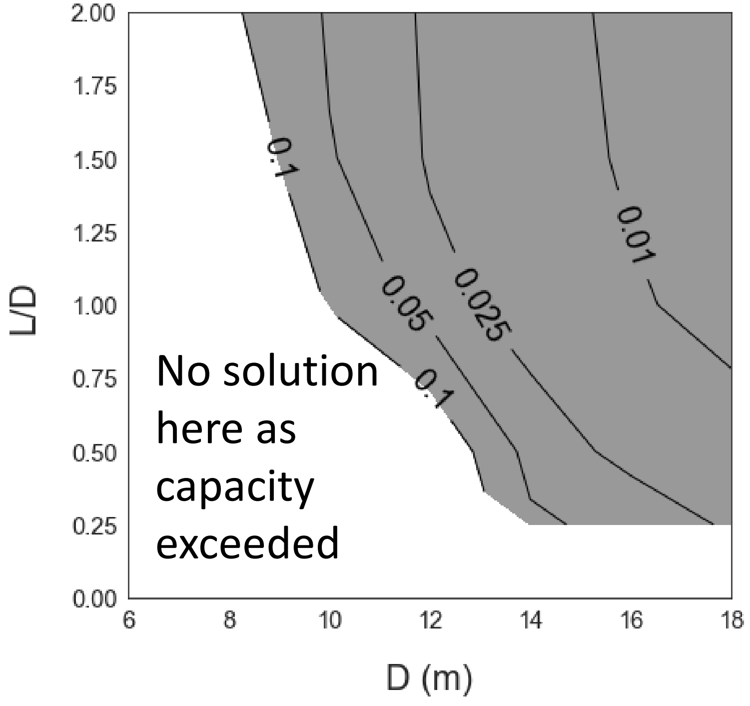
Suction pressure as per Houlsby & Byrne (2005)

Feasible Solutions

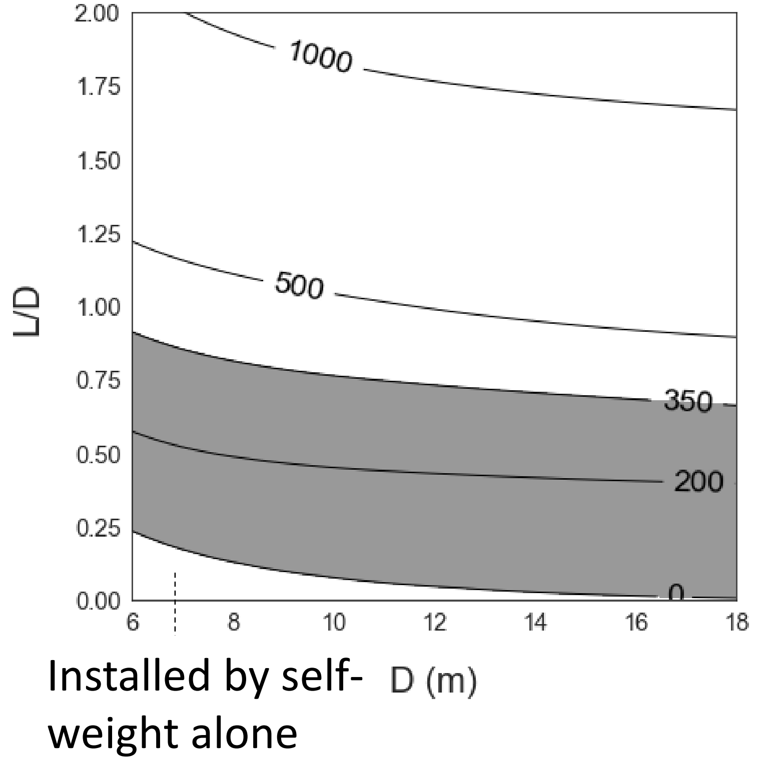
Contour plots of d_{ULS}



Contour plots of θ_M



Contour plots of p_{suction}



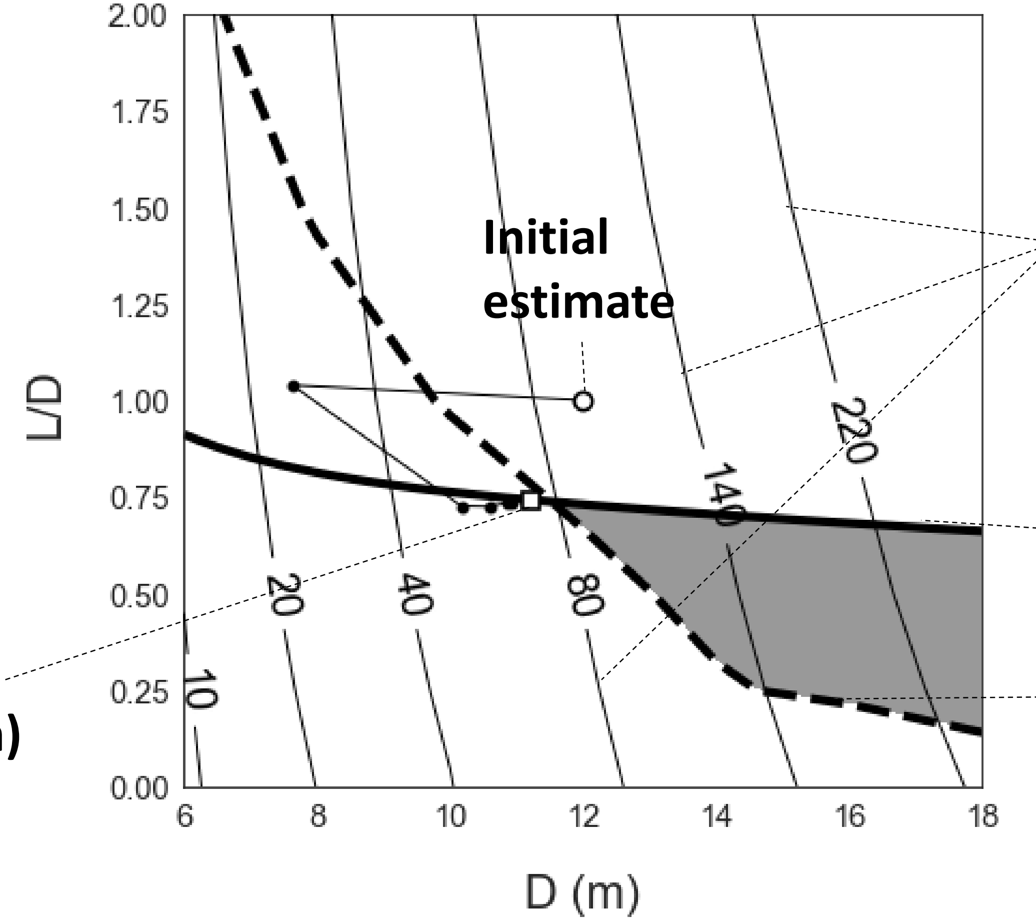
Search space: $0 \leq \frac{L}{D} \leq 2, 6 \leq D \leq 18$

Shaded regions: Feasible regions

Optimal Solution

- Overlay the constraints for SLS, ULS & installation
- ULS & installation governs

Shaded region: Feasible region under both SLS and ULS conditions



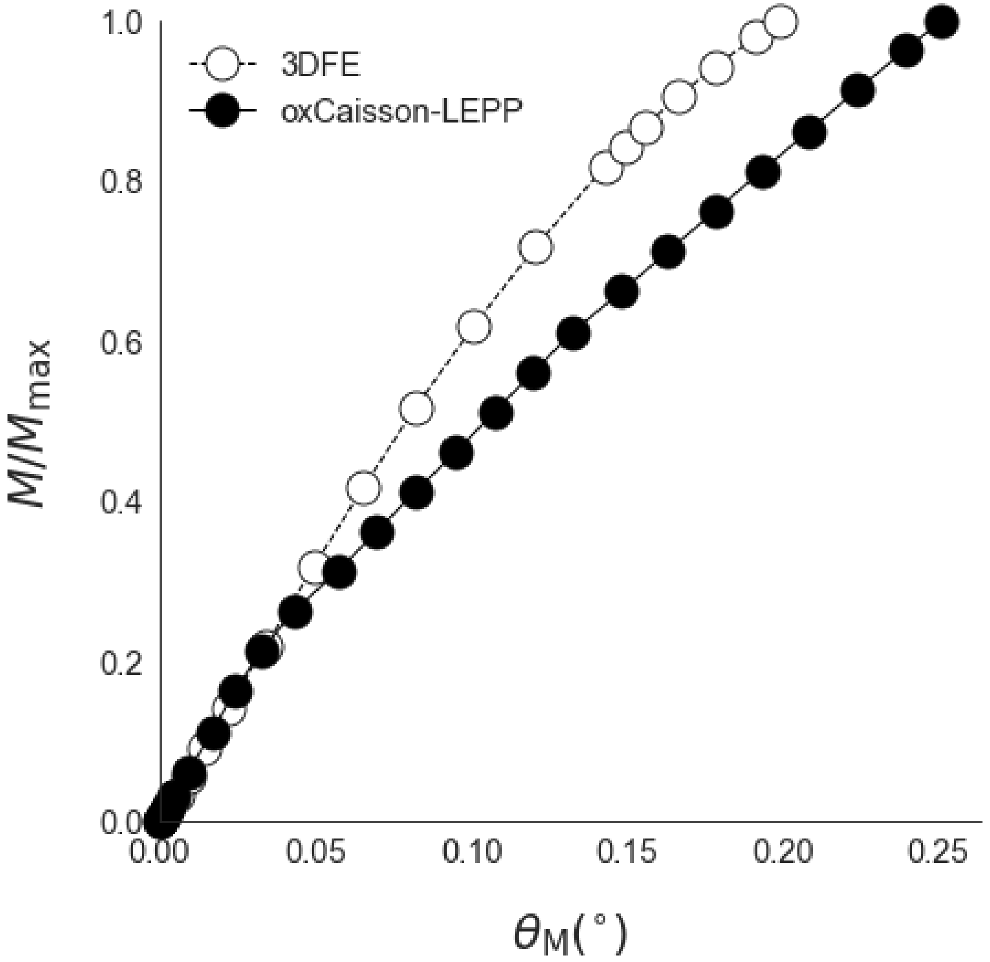
Volume of caisson

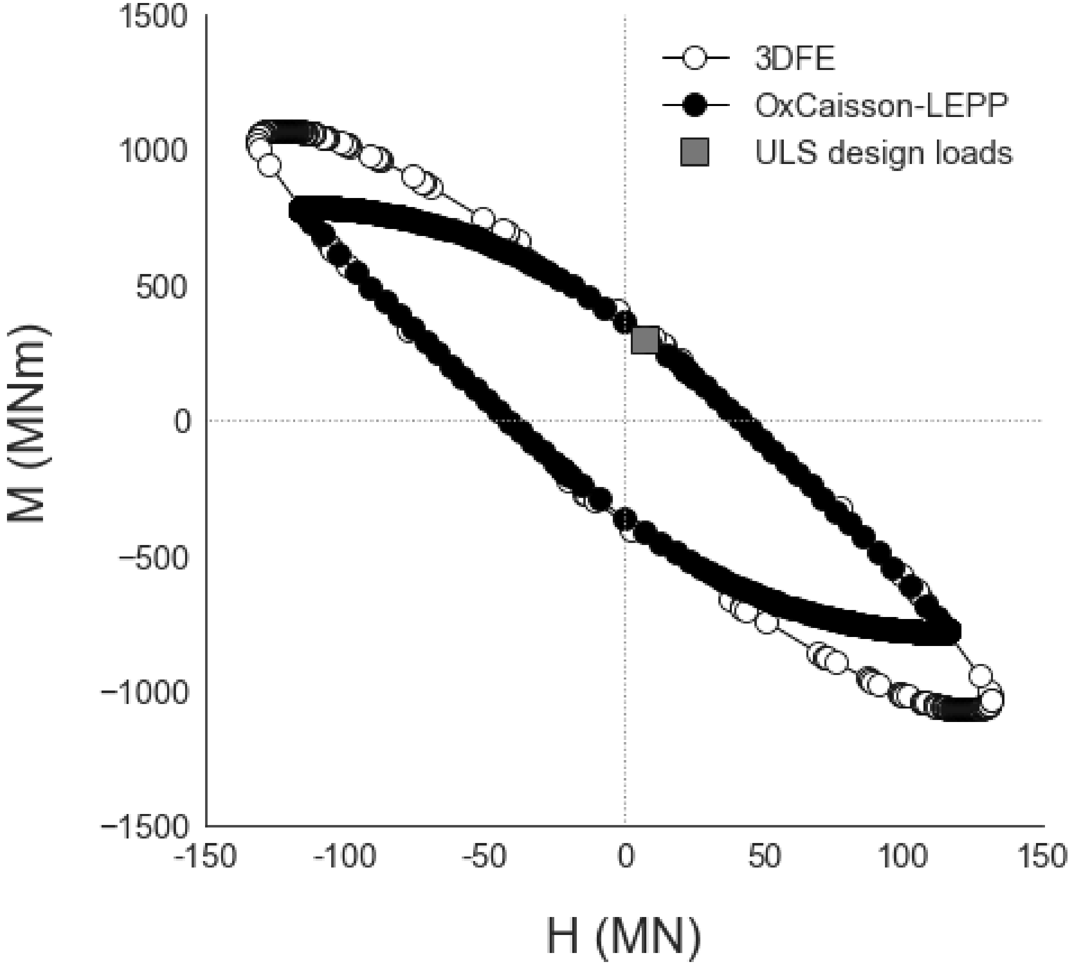
Installation constraint

ULS constraint

Optimal solution (using Matlab fmincon)

OxCaisson-LEPP 3DFE Check

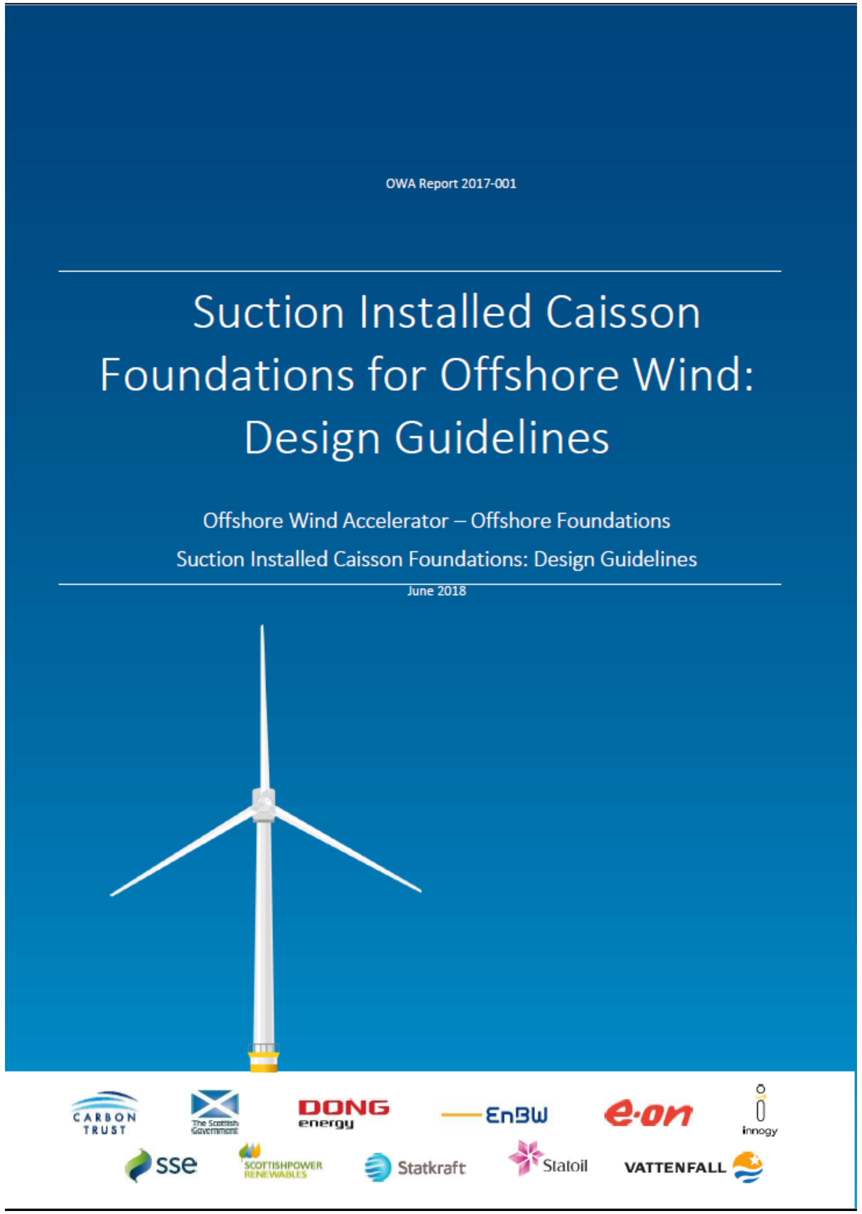




Conclusion

- Optimisation of offshore wind farm designs require fast design methods
- oxCaisson is a fast design method for suction caissons that approximates the 3DFE predictions for ULS and SLS assessments
- Case study demonstrates the use of oxCaisson-LEPP to optimise the suction caisson design automatically and quickly

2019 Design Guidelines


OWA Report 2017-001

Suction Installed Caisson Foundations for Offshore Wind: Design Guidelines

Offshore Wind Accelerator – Offshore Foundations

Suction Installed Caisson Foundations: Design Guidelines

June 2018

$$\sqrt{\left(\frac{H}{h_0V_0}\right)^2+\left(\frac{M}{m_0DV_0}\right)^2-\frac{2aHM}{h_0m_0DV_0^2}}-4\frac{V}{V_0}\left(1-\frac{V}{V_0}\right)=0$$