Proceedings of ISFOG 2025
5TH INTERNATIONAL SYMPOSIUM ON
FRONTIERS IN OFFSHORE GEOTECHNICS
Nantes, France | June 9-13 2025

ISBN 978-2-85782-758-0

Cloud-Based Freeware Webapps for Offshore Foundation and Anchor System Design

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ABSTRACT: This paper sets out capabilities of a new cloud-based platform of freeware webapps supporting a range of digital tools for offshore foundation and anchor system design. The platform architecture enables a range of tools to be hosted including data-rich and machine learning tools, and import and export of large data sets permitting parametric analyses. The platform enables live, interactive visualization of design outcomes with data export functionality for retention and further analysis. The calculation tools are based on published research outcomes and include (i) characterization tools for predicting derived soil properties for design input; (ii) bearing capacity formulations for a range of foundation geometry, soil types and loading conditions; (iii) multidirectional failure envelopes that feature single-objective optimization, with and without consideration of consolidation strength gains; (iv) whole-life response at element level and for boundary value problems; (v) prediction of anchor loads from a variety of mooring systems; and (v) a GIS-based marine spatial planning tool. All the tools are intended for use at concept design stage to inform on architecture or configuration selection and initial sizing of components. An underpinning philosophy of the tools is to provide quick outputs for idealized conditions to support initial design decisions. The new platform has overarching value in streamlining research outputs into design practice, to promote the uptake of new design methods and increase the accessibility of frontier techniques of offshore geotechnical design.

Keywords: design tools; optimization; software; machine learning

1 BACKGROUND

The Web Apps for Engineers (WA4E) tools www.webappsforengineers.com are web-based implementations of design methods and formulae to support concept design decisions for offshore foundations and anchoring systems. The tools support (i) novel analysis methods, including optimization approaches to flip the traditional calculation format and directly determine the required design to meet the necessary factor of safety for given seabed and environmental loading conditions; (ii) novel foundation or anchoring system configuration, e.g. tolerably mobile foundations and moorings with load reduction devices; (iii) derivation of input parameters for design, including data-rich machine learning supported tools to derive engineering parameters from soil classification properties; and (iv) a shifting basis of design, for example evolution of geotechnical properties and foundation response through the design life via a whole-life geotechnical design framework.

The motivation for the WA4E freeware webapps platform is to make novel design approaches and methods accessible to practising engineers and the research community. It is the intention that the ability to trial new methods and technologies will enable engineers and the sector to gain confidence in adopting them, promote transparency, inform the design tools to suit industry needs, and to test and validate methods. Other geotechnical freeware and webapps are also available that support this overarching philosophy of accessibility and transparency (e.g. ABC (Martin 2003) and Geocalcs (Doherty 2017, Doherty et al, 2018), both of which are linked to in the Web Apps for Engineers (WA4E) www.webappsforengineers.com platform.

A new cloud-based version of WA4E has been launched (Figure 1), and is introduced in this paper. The cloud-based architecture and functionality of the platform are outlined followed by a showcase of selected new apps.

2 CLOUD-BASED WA4E ARCHITECTURE & FUNCTIONALITY

The original Web Apps for Engineers (WA4E) freeware platform, launched in 2017 (Gourvenec et al. 2017), comprised JavaScript implementations of published code and formulae, which ran browser-side via a graphical user interface (GUI). The platform has since attracted > 12,000 independent users across the globe from industry and academia. Additional design tools have been added to the platform periodically due to further research outcomes or requests from users, but the platform architecture and functionality had remained unchanged.

A new cloud-based version of WA4E has been launched enabling a wider range of calculation tools to be hosted – particularly data rich and machine learning tools. The new cloud-based webapps are formulated with a Python web applications Django server using the Django REST framework to create an application programming interface (API), which the existing JavaScript front-end can interact with. In addition to the enhanced capability for data rich tools provided by the server-side architecture, the Django back-end allows for Python code to be run from WA4E. Researchers are much more likely to write code in Python than JavaScript since Python has stronger scientific capabilities and is more straightforward to work with. Therefore, Python code written by researchers can be run from WA4E without needing to be translated to JavaScript. Not translating research code to JavaScript saves time but, more importantly, also reduces the likelihood of human error and therefore increases the robustness of the web apps.

New calculation tools have been added that support emerging design approaches or basis of design. These include apps for whole-life geotechnical design (Gourvenec 2020, Gourvenec 2022, Laham et al. 2024); tolerable mobility (Cocjin et al. 2017); derivation of engineering parameters from machine learning methods (Charles et al. 2023, Charles & Gourvenec 2024); novel mooring system configurations (Festa et al. 2023, 2024, 2025); and a GIS-based marine spatial planning tool for offshore developments (Putuhena et al. 2023a & b). The Python functionality enabled by Django server architecture has been used by all of the new apps. Implementations of the pre-existing design tools have been updated, removing deprecated code and streamlining the background maths across the apps. The GUI has been modernised and restyled with modular WebComponents built on the Lit framework. All tools enable export of results for data retention and further post-processing via Plotly. The cloud-based platform also includes a new batch run capability, such that the user can import a text file of multiple design scenarios and export tabulated output rather than executing calculations individually through the GUI.

A user login system uses the Token Authentication submodule of the Django REST framework, such that an authentication token is created upon login and destroyed upon logout. Nginx is used as a reverse proxy which allows for a single entry point and improves security to the servers. Privacy for users is assured as no data input or output regarding calculations are visible or retained on the platform to admin. Basic analytics track which apps are used but not linked to users.

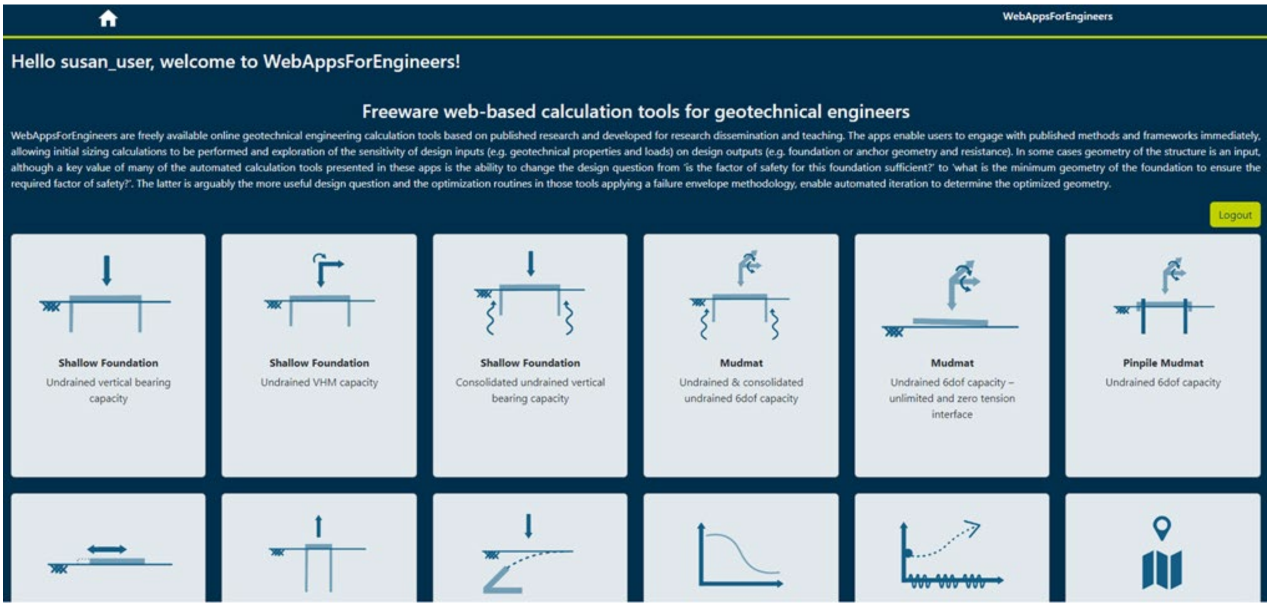

Figure 1. Landing page for cloud-based WA4E www.webappsforengineers.com

3 SELECTED WA4E DESIGN TOOLS

A selection of new design tools available on the cloud-based WA4E platform are highlighted here that showcase a range of capabilities, including (1) GeoEvolve, enabling prediction of cycle-by-cycle evolution of soil properties under episodic cyclic loading; (2) mooring line tools enabling prediction of anchor loads for whole-life design, including an artificial neural network (ANN)-based surrogate model for predicting whole-life time histories; and (3) G-γ sand, an ANN predictive tool outputting stiffness degradation with strain from simple classification data, trained on extant laboratory element test data. Apps ported from the original browser-side platform are showcased in previous publications, and the reader is directed to those for illustration of their capability (e.g. Gourvenec 2020, 2023).

3.1 GeoEvolve

The GeoEvolve app captures changing strength and stiffness of normally consolidated soils under whole-life loading conditions involving episodes of cyclic shearing and consolidation (Figure 2). Users can set the cyclic shear amplitude (τ/s_u), number of shearing cycles (n_{ep}) and number of episodes (N_{ep}) applied to an element of soil and see how the undrained strength (s_u), stiffness (κ and G) and void ratio (e) evolve with each episode. The app also displays the resulting effective stress path in e vs $\ln\sigma'_v$ space as the element of soil 'zig-zags' towards stronger states. The theoretical episodic cyclic loading framework underpinning the app is based on critical state principles and S-N curves (Laham et al. 2024a), derived from a suite of laboratory element direct simple shear tests (Laham et al. 2024b).

The app outputs a range of data that is presented graphically, and can be exported as a csv file. Selected examples are shown in Figure 3.

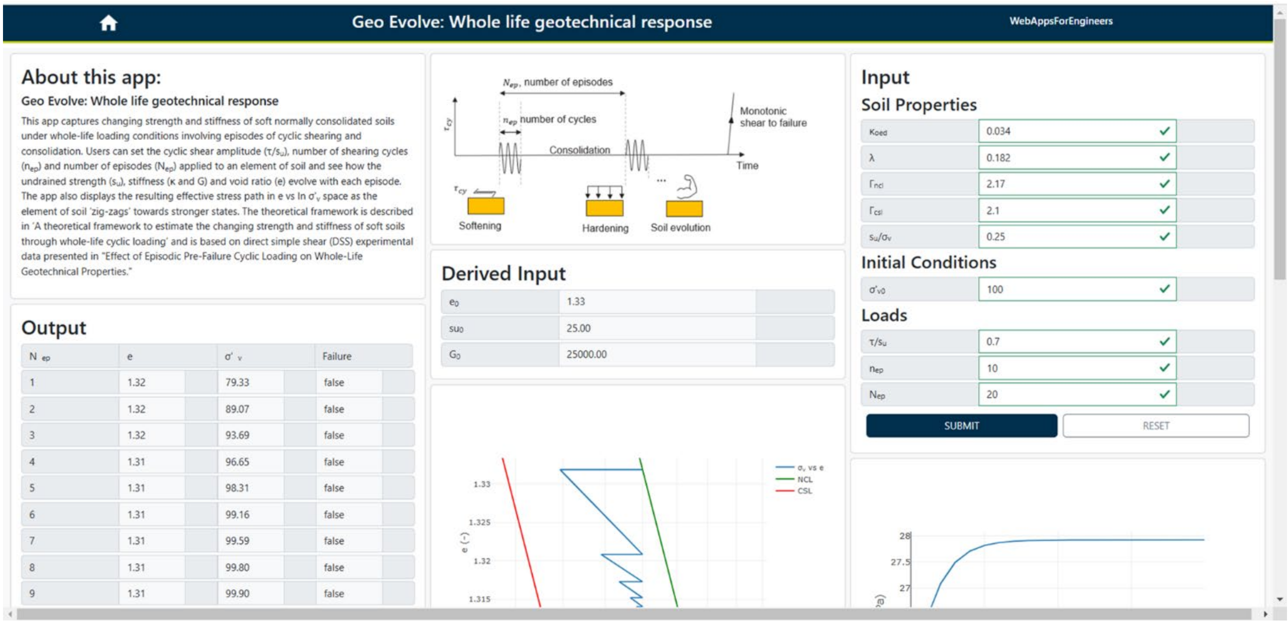

Figure 2. GeoEvolve calculation tool

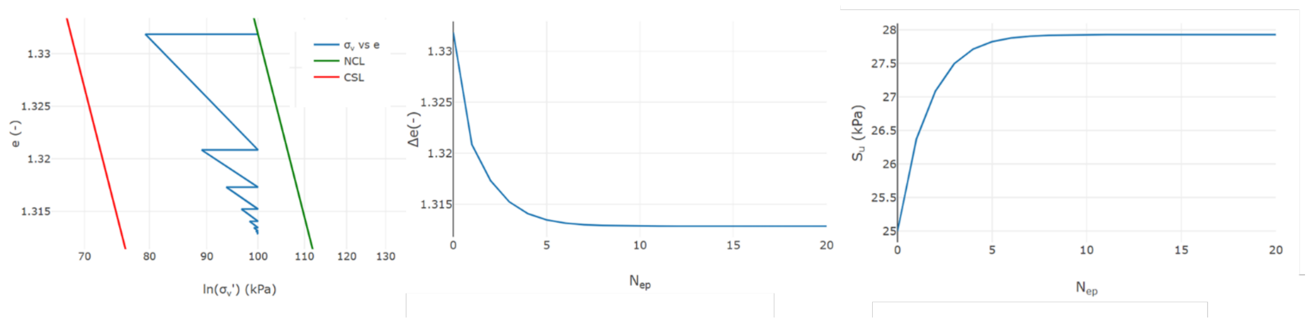

Figure 3. Examples of GeoEvolve output (a)stress-volume relationship, (b) change in void ratio & (c) evolution of strength

3.2 Mooring line; Quasi-static & dynamic

The quasi-static mooring line app solves equations for taut, semi-taut and catenary moorings with and without a load reduction device (LRD) – an extensible section that enables reduction of peak loads being transmitted to the mooring line and anchor. Users select water depth, mooring line parameters, pre-tension, LRD type and parameters, and the app outputs a visualisation of the initial static mooring configuration, stiffness response to quasi-static platform offset, and vertical and horizontal components of mooring line force that can be converted to mudline or anchor loads for geotchnical analysis (Figure 4).The app is based on an extension of an analytical model of non-linear load reduction devices for catenary moorings (Festa, et al. 2022).

The dynamic mooring line app provides time history results of fairlead and anchor loads for any environmental loading parameters and mooring configuration (taut, semi-taut, catenary), from a surrogate model using neural networks trained on fully-coupled dynamic analyses of the IEA 15 MW Volturn-US FOWT (Festa, et al. 2024, 2025) (Figure 5). These neural networks provide load time histories 50,000 times faster than with traditional dynamic analysis software (Festa, et al. 2025). The time histories can provide input to whole-life geotechnical design calculations, such as to minimize anchor size (e.g. Kwa et al. 2023).

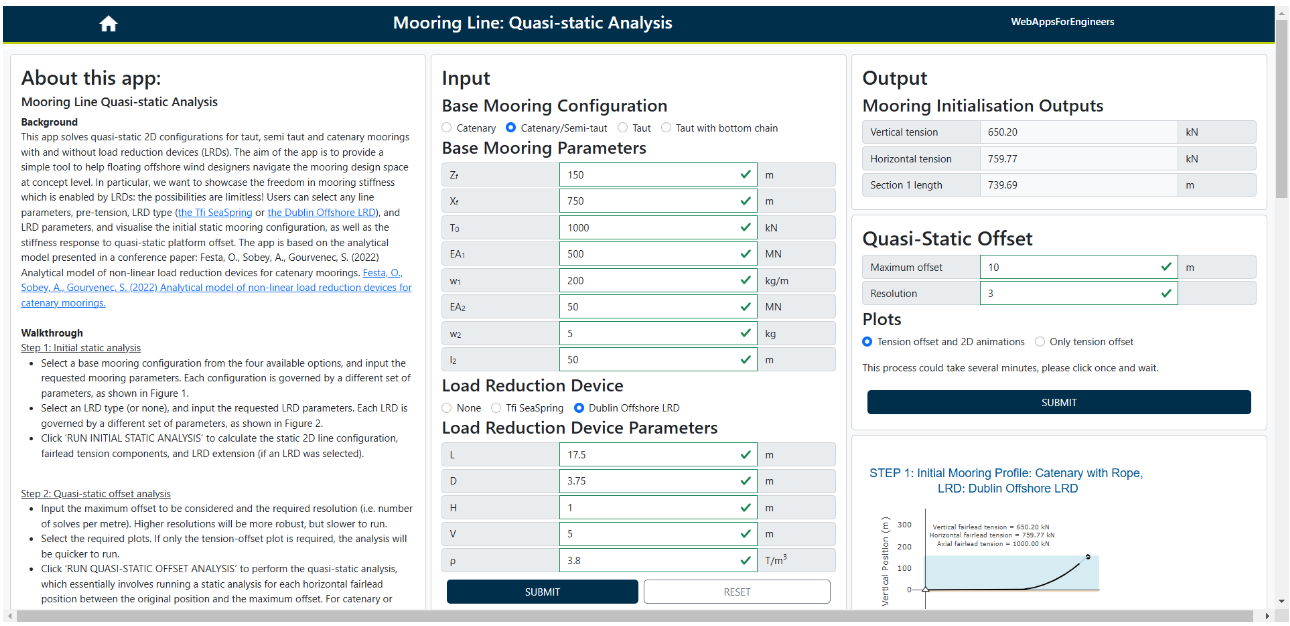

Figure 4. Example of mooring system initialisation tool incorporating a load reduction device

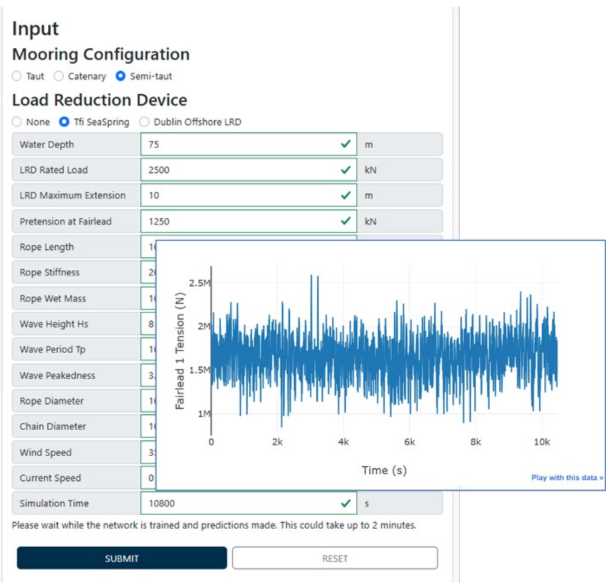

Figure 5. Input panel and time-history output of mooring line load from ANN surrogate dynamic mooring line app

3.3 G-γ sand

A shear stiffness degradation curve for sands can be created based on an arbitrary number and combination of input parameters using an artificial neural network (Figure 6). The user can select and input any number and combination of the following parameters: mean effective stress (p), mean effective stress (p), over consolidation ratio (OCR), void ratio (e), relative density (Dr), average grain size (D_{50}), uniformity coefficient (Cu) and initial elastic shear modulus (G_0). The relevant dataset is then loaded and filtered and a neural network is trained, generating an output curve of shear stiffness vs strain. The geotechnical basis and performance of the ANN tool is described in Charles et al. (2023) and the architecture in Charles & Gourvenec (2024).

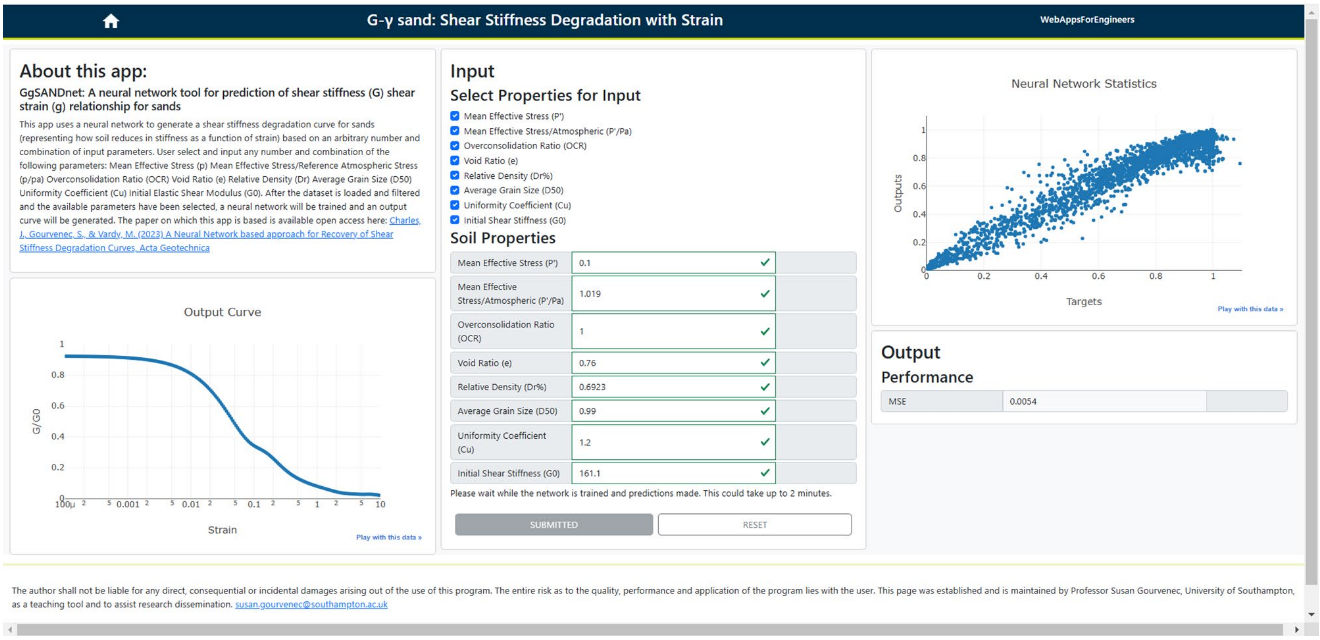

Figure 6. Example of stiffness degradation curve predicted by the G-γ sand artificial neural network tool

4 CONCLUSIONS

A new cloud-based platform of freeware webapps supporting a range of foundation and anchor system design has been presented. The architecture of the platform has been outlined alongside an overview of the calculation tools available, and the new batch run functionality permitting parametric analysis. Selected apps have been highlighted that showcase new capability and functionality, including whole-life geotechnical design and data-rich machine learning tools. The platform is open access, free to use by anyone to support teaching, research or engineering practice. Webappsforengineers.com, along with other freeware web app tools, provide a vital pathway to streamline research outputs into design practice, to promote the uptake of new design methods and increase the accessibility of frontier techniques of offshore geotechnical design.

AUTHOR CONTRIBUTION STATEMENT

First Author: Conceptulization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Visualisation, Writing- Original draft. **Second & Third Authors**: Data curation, Formal Analysis, Investigation, Methodology, Software, Validation, Visualisation, Writing- Review.

ACKNOWLEDGEMENTS

Susan Gourvenec is supported by the Royal Academy of Engineering under the Chairs in Emerging Technologies scheme. The work presented in this paper forms part of the activities of the Centre of Excellence for Intelligent & Resilient Ocean Engineering, IROE, (www.southampton.ac.uk/iroe). Philippa Broadbent and Philip Grylls′ contributions to this work were supported by the Research Software Group (RSG) at the University of Southampton, funded through a UKRI EPSRC Impact Acceleration Award. Industry collaboration with Geowynd provided valuable input and feedback to the design tools and platform.

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