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State of the art subsea foundation design - supporting industry needs

Professor Susan Gourvenec

Centre for Offshore Foundation Systems, University of Western Australia
ARC Centre for Geotechnical Science and Engineering
Energy and Minerals Institute

SUT Technical Meeting, 26 February 2014

Subsea development

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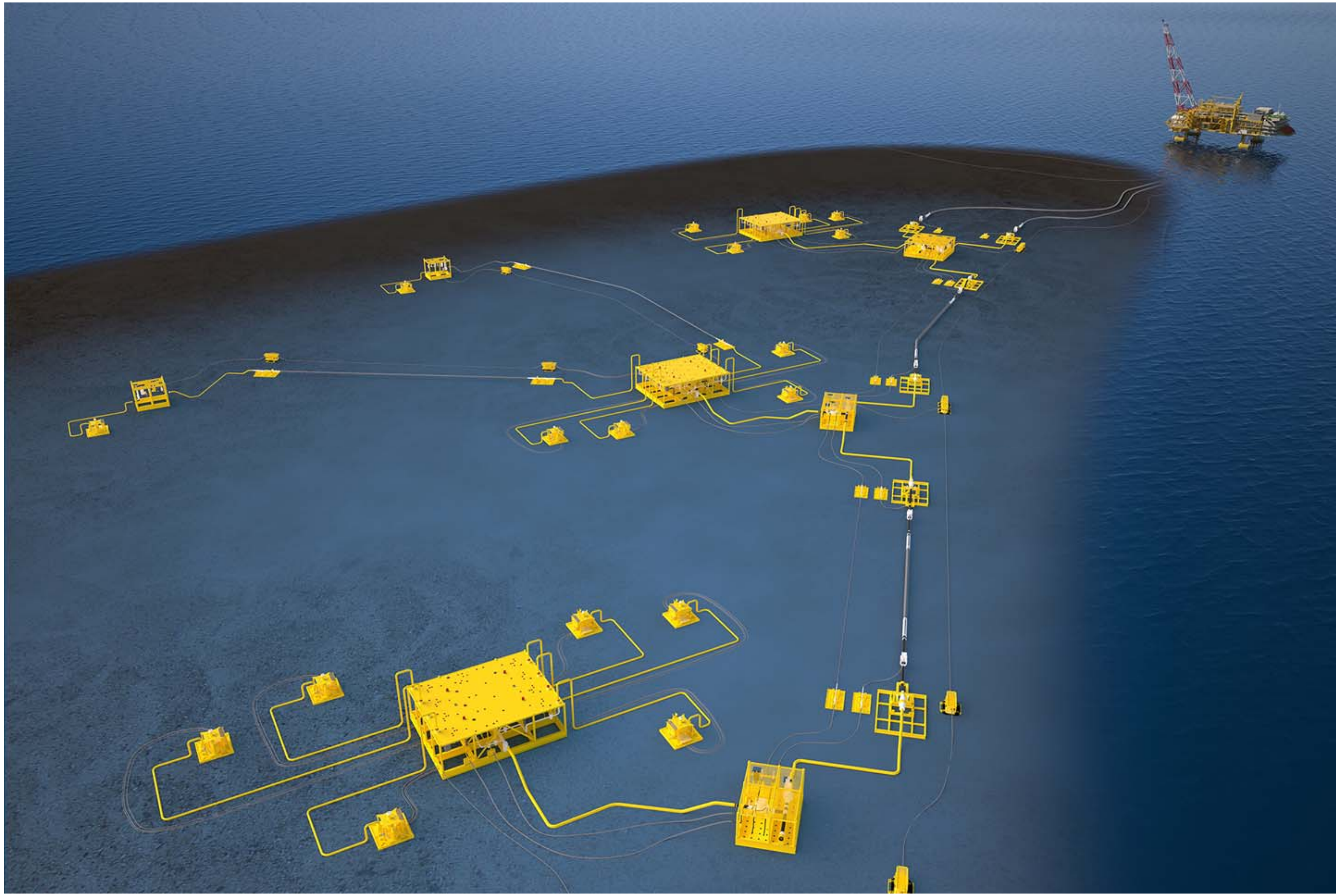

Julimar field, Apache. www.apachecorp.com

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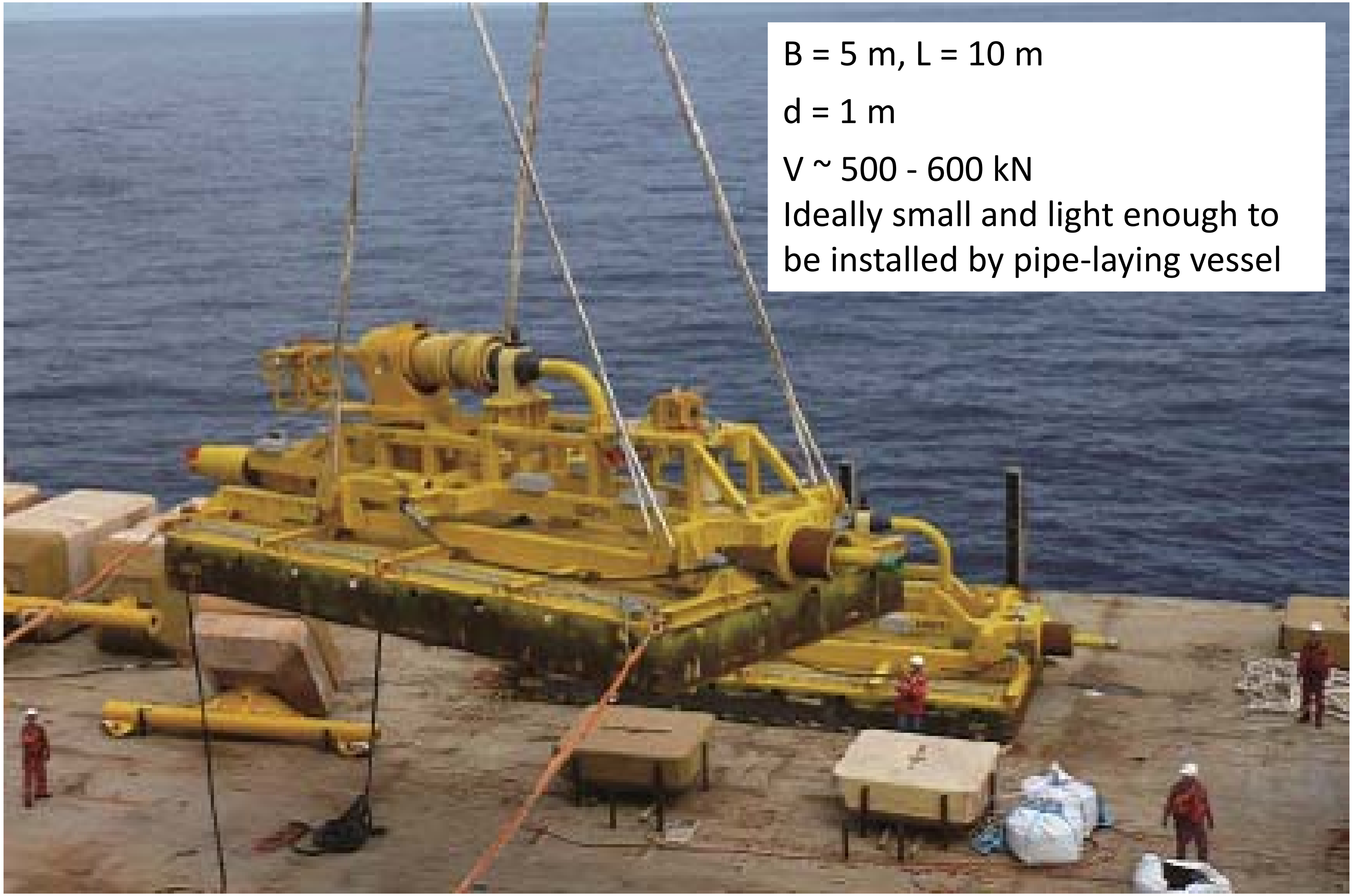
Subsea structure



B = 5 m, L = 10 m

d = 1 m

V ~ 500 - 600 kN

Ideally small and light enough to be installed by pipe-laying vessel

Pazfloor, Angola. Image courtesy of Subsea 7

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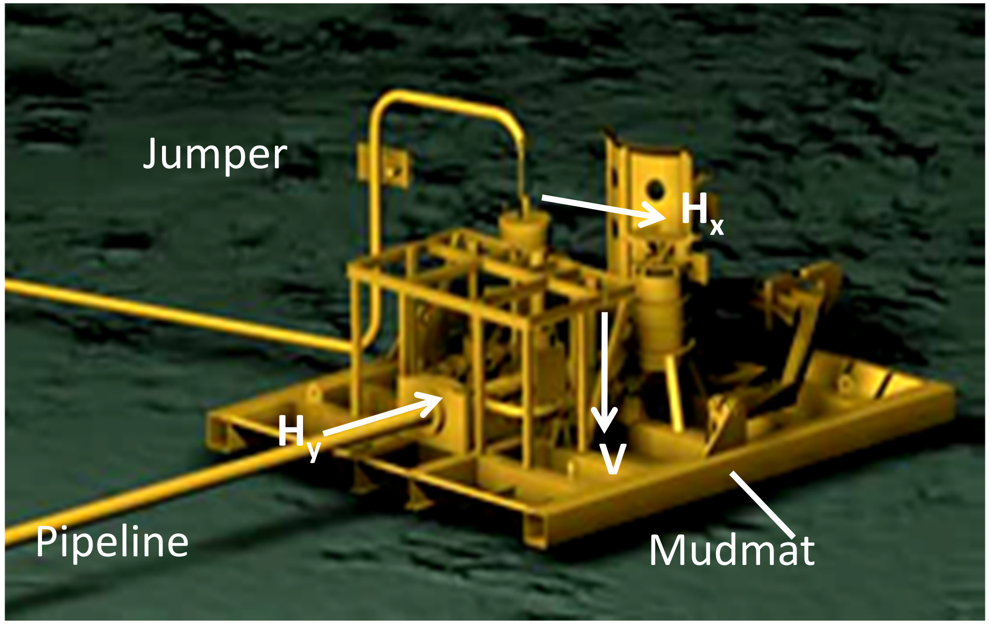
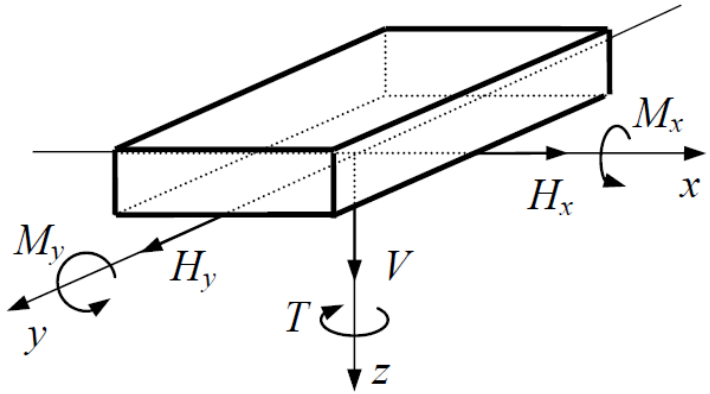
Subsea foundation - VH2M2T

- Subsea mudmats subjected to loading in 6 dof
- Self-weight, biaxial horizontal loads (from thermal expansion of pipelines)
- Vertical and horizontal eccentricity of loads = biaxial moments and torsion





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The geotechnical design issue

- Classical bearing capacity theory
  - $q_{ult} = (\pi + 2)s_u$ x lots of reduction factors, e.g. s_c, d_c, i_c, B', L', F, κ
  - VHM, no torsion, and HM poorly predicted
  - Output = single allowable vertical load or bearing pressure
  - No indication of effect of different load components on proximity to failure.

- Conventional design method
  - Too large for pipelaying vessel to install.
  - Require second vessel on site = $$$ ☹

- Optimized design method
  - Small enough for pipelaying vessel to install.
  - ☺

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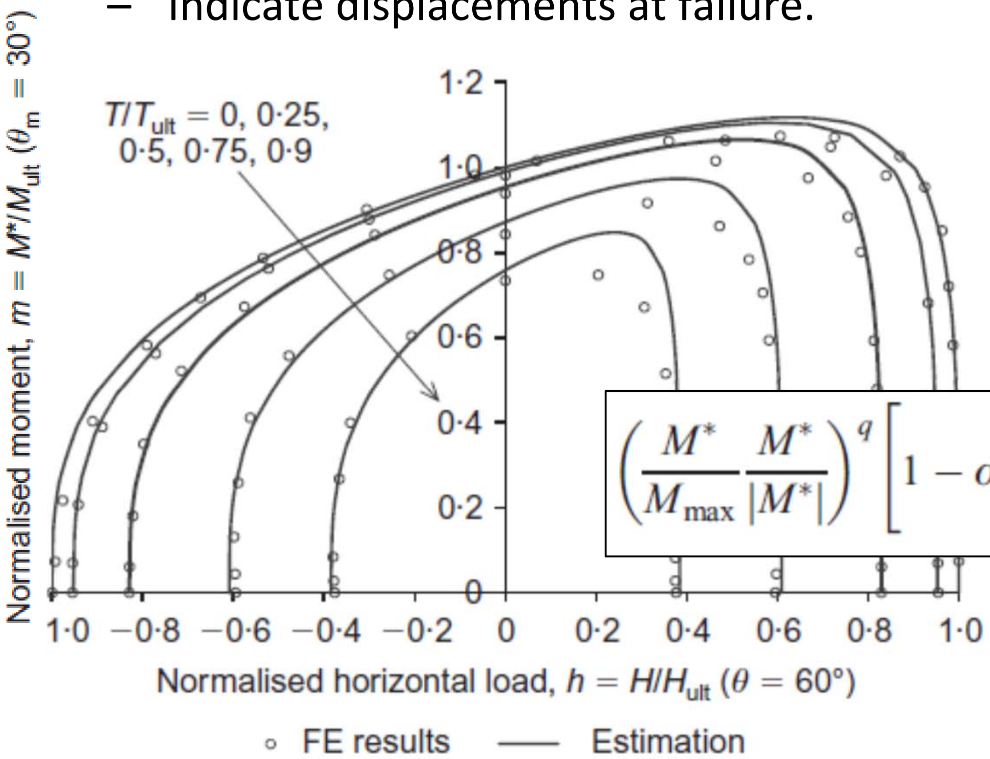
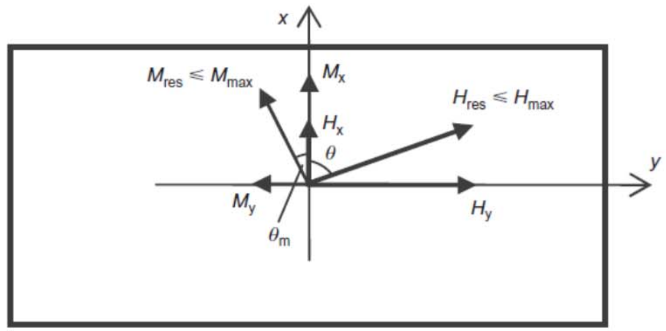
1. Alternative design method

- Failure envelope design method
  - Explicitly account for effect of applied loads, V, H_x, H_y, M_x, M_y, T
  - Explicitly account for effect of geometry , B/L, d/B
  - Explicitly account for shear strength profile, kB/s_{u0} , surface crust
  - Determine how individual variables affect the design outcome.
  - Indicate displacements at failure.





$$\left(\frac{M^*}{M_{\max}}\frac{M^*}{|M^*|}\right)^q\left[1-\alpha\frac{H}{H_{\max}}\frac{M^*}{|M^*|}+\beta\left(\frac{H}{H_{\max}}\right)^2+\left(\frac{H}{H_{\max}}\right)^2=1\right.$$

Feng et al., 2014, Géotechnique

Caveats

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- Be wary of oversimplification.
- Choice of appropriate s_u is central to calculation – affected by various conditions, inc. cyclic loading.
- Assumptions of undrained load response.

But …

- Neat tool for preliminary sizing.
- Indicates influence of design input independent variables.
- Augment with more detailed analysis for detailed design.
- Tool demonstrates how improved site investigation data can have significant impact on design.

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Industry impact

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Groundbreaking geotechnics

In 2011, Subsea 7 commenced accelerated development in the field of Geotechnics in two areas of great significance for our clients' deepwater operations, how seabed soils and pipelines interact, and how an enhanced appreciation of soil behaviour and failure mechanisms can optimise foundation design, particularly for very soft deepwater clays.

Pipelines

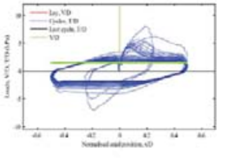
Subsea 7 actively participates in the Safebuck series of JIPs - currently in its third phase - but we have also internally funded work investigating the dynamic embedment (and hence friction and stability) of pipes laid on soft clays which are typically found at the deepwater sites where we work.

Another key challenge being addressed is an improved understanding of the behaviour of carbonate sediments which are widespread in some developing oil and gas-rich regions such as Australia.

Carbonate-rich soils exhibit different behaviour to their non-carbonate counterparts, so Subsea 7 undertook a study to investigate the response of carbonate soils to cyclic pipe loads by model testing in a geotechnical centrifuge.

Model pipe set up for axial friction test

The results of this study are counter-intuitive to those predicted by classical soil mechanics, and the work represents a significant step forward in evolving a new constitutive model to describe the behaviour of carbonate soils.



Apparent friction derived from cyclic axial friction tests

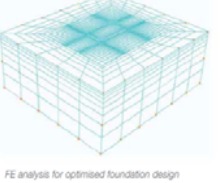
Foundations

In our subsea construction business, there is constant pressure to optimise foundation design to be as efficient as possible in terms of installation without compromising functionality.

Subsea 7 has produced recent research at the highly respected Centre for Offshore Foundation Systems at the University of Western Australia into an optimised design methodology that has led to the possibility of reducing the size of shallow foundations such as PLET mudmats by 20%, or alternatively able to withstand larger jumper loads.

The geotechnical engineer is always interested in finding the most critical failure mechanism of a foundation.

Subsea 7 has teamed up with the university to develop a new 3D analysis tool which could potentially halve the engineering hours spent designing foundations under complex loading.



FE analysis for optimised foundation design

Mudmats for PLET applications

Looking to the future...

Emerging challenges in the geotechnical industry are likely to include:

- developing and improving the constitutive model for carbonate soils and applying it to foundation and pipeline design
- how to quantify the degrading effects of solid hydrate and hydrate dissociation on soil properties
- further optimisation of foundation designs as large and heavy processing facilities are moved subsea
- developing design methods for ultra-deepwater soils where soil strength is more dominated by viscous behaviour than traditional shear strength
- finding novel and effective ways to protect subsea infrastructure in the Arctic or ice-prone regions.

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2. Hybrid subsea foundation

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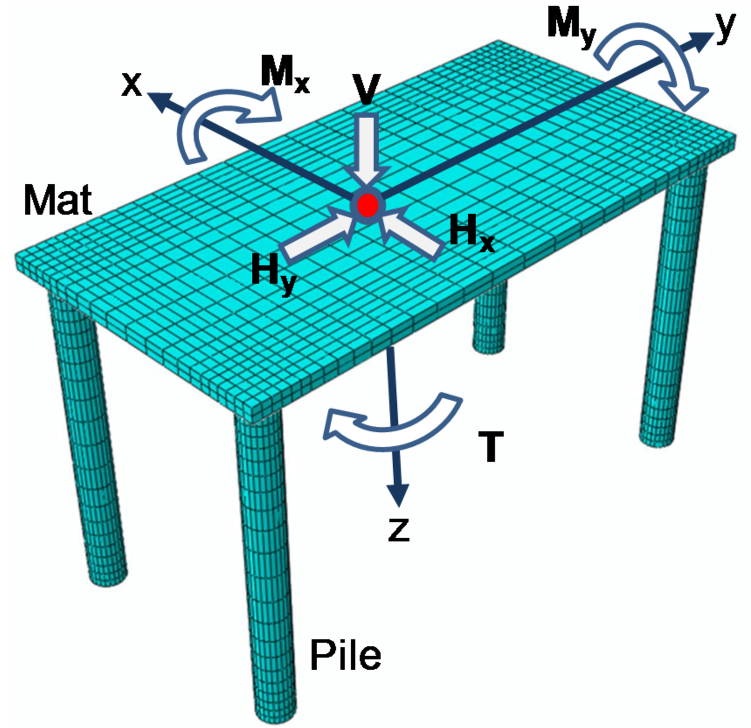
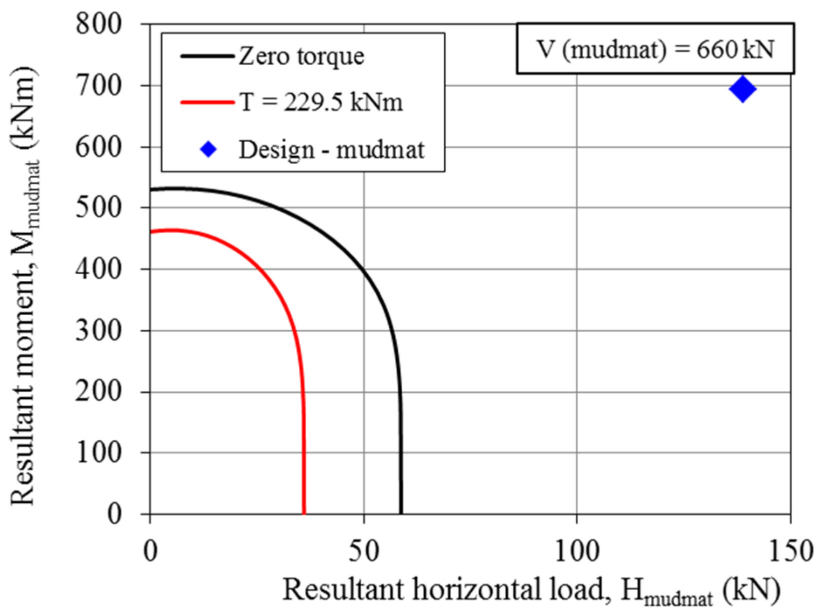
- Mudmat with corner pin piles
  - Increase in 6 dof load capacity over mat alone, in particular lateral and torsional resistance.
  - Smaller footprint sizes.





Gaudin et al., 2011, SUT London
Dimmock et al., 2013, ASCE JGGE

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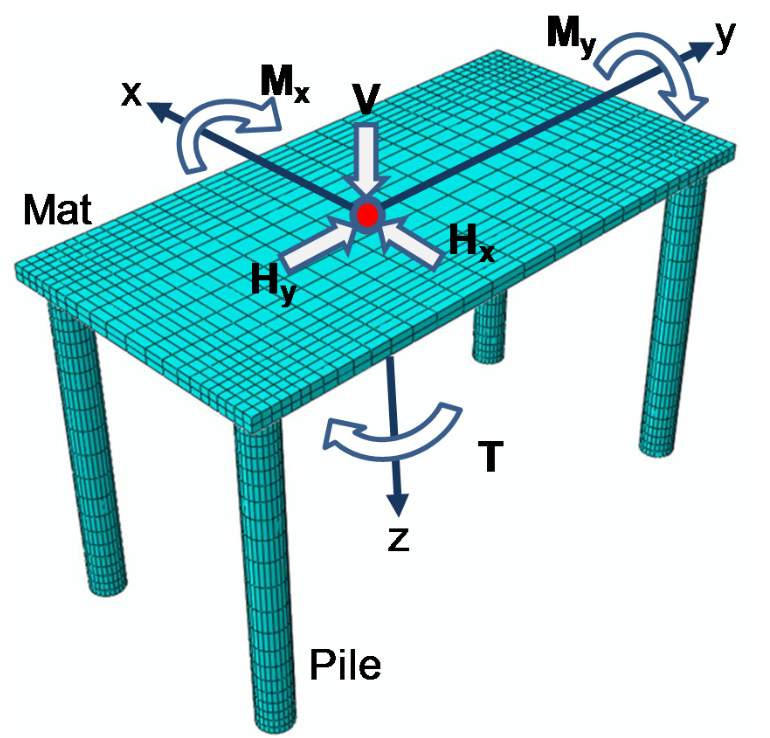

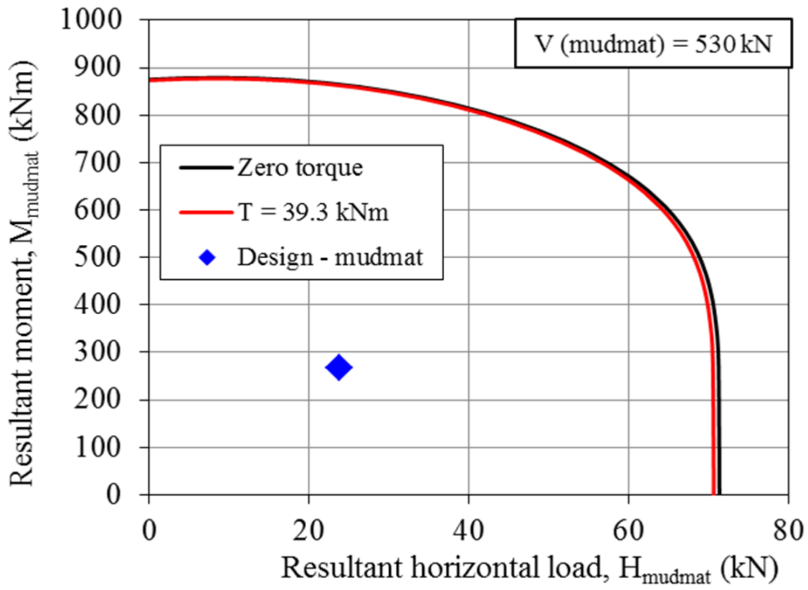

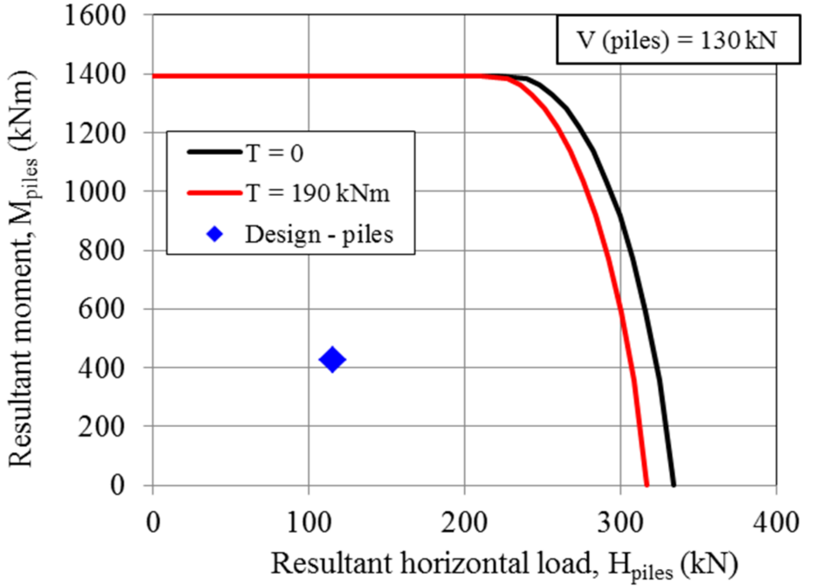

Gaudin et al., 2011, SUT London
Dimmock et al., 2013, ASCE JGGE

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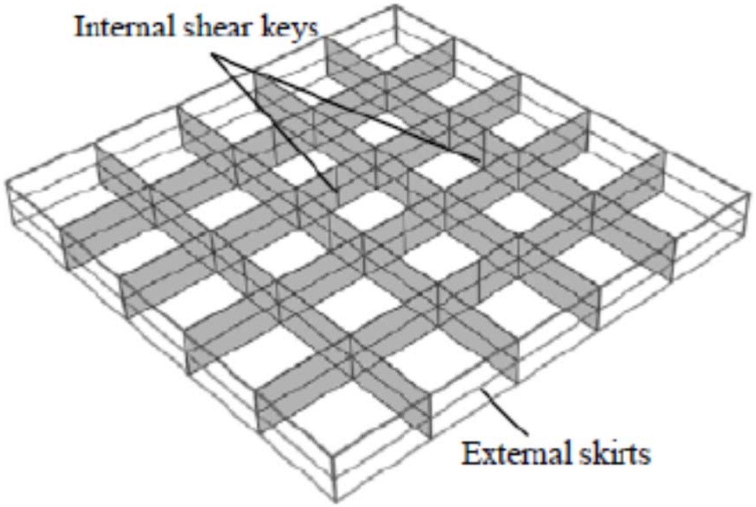
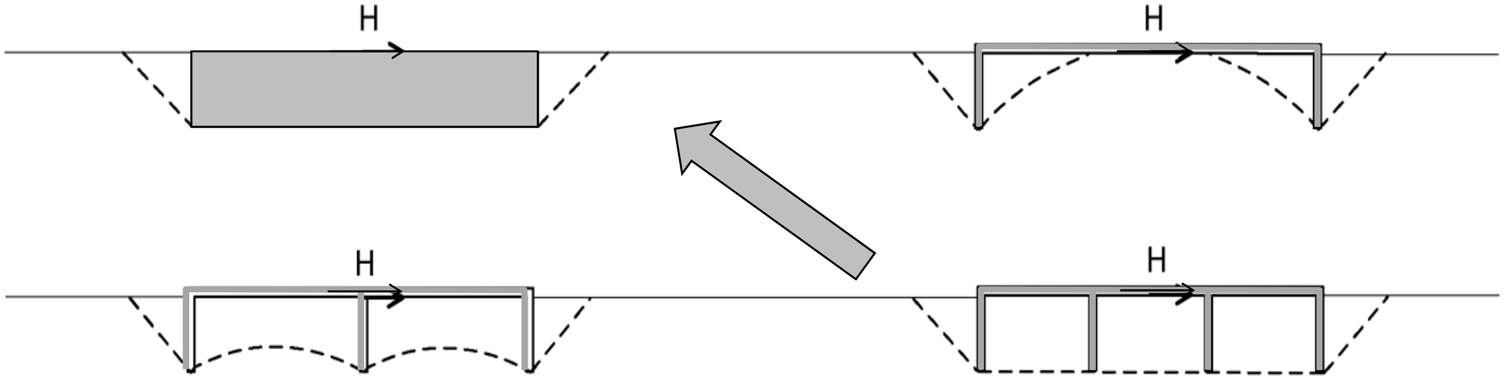
3. Internal skirt spacing

- Optimal spacing of internal shear keys
  - Prevent shearing within the confined soil plug.





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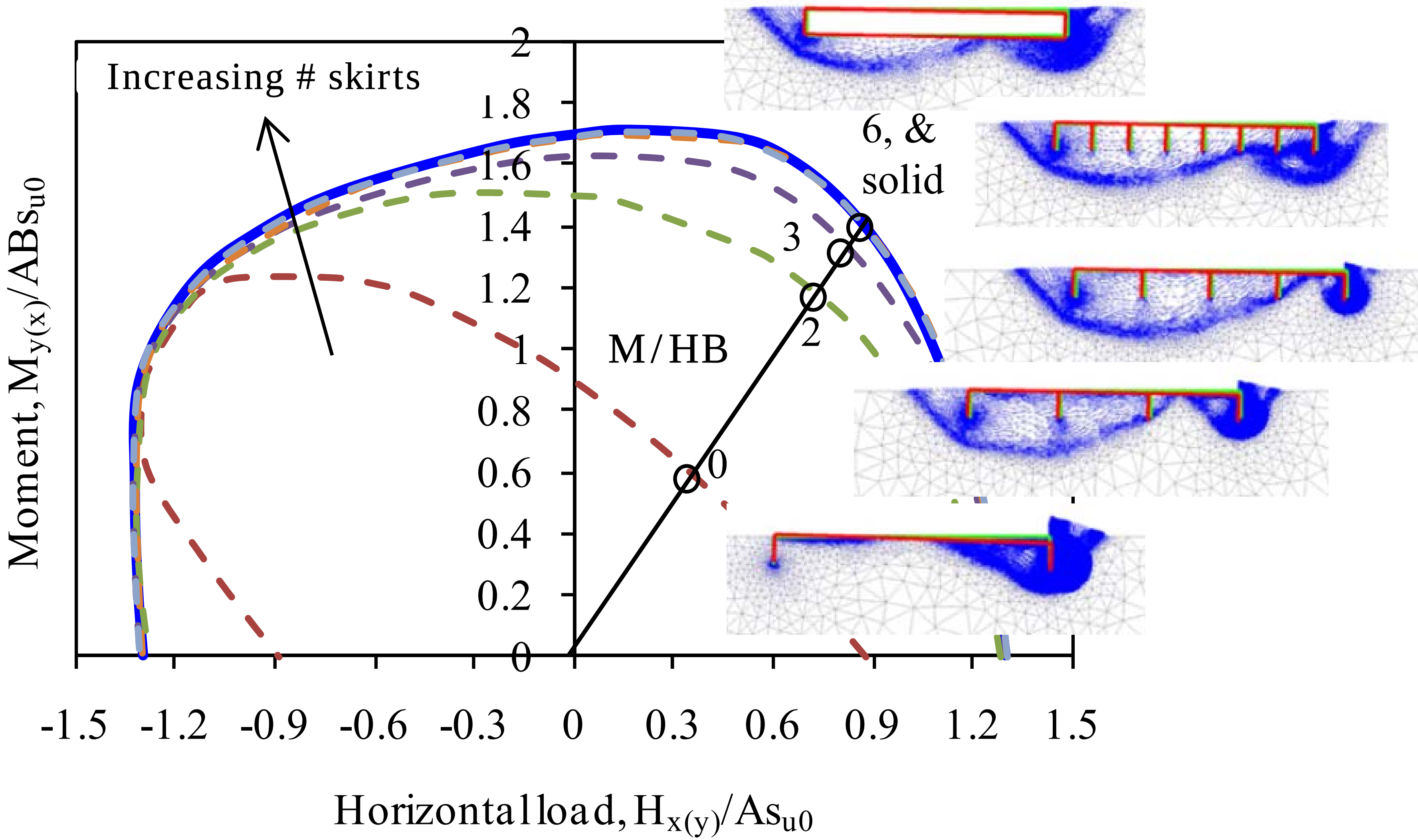
Internal skirt spacing

- Failure envelopes & failure mechanisms



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Internal skirt spacing

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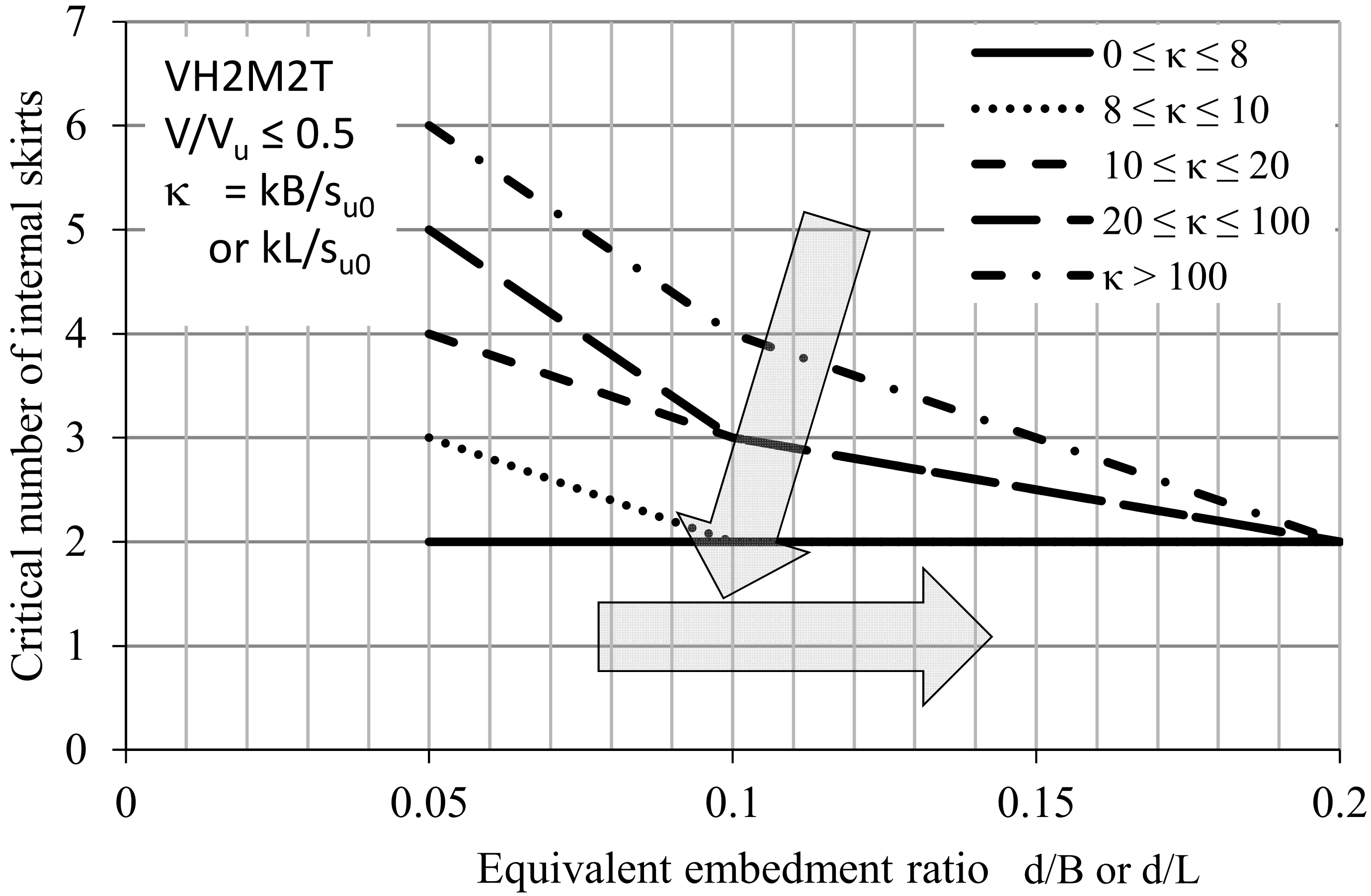
- Design charts



Feng & Gourvenec, OMAE, 2013
Mana et al., ASCE JGGGE, 2012

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4. Consolidated shear strength

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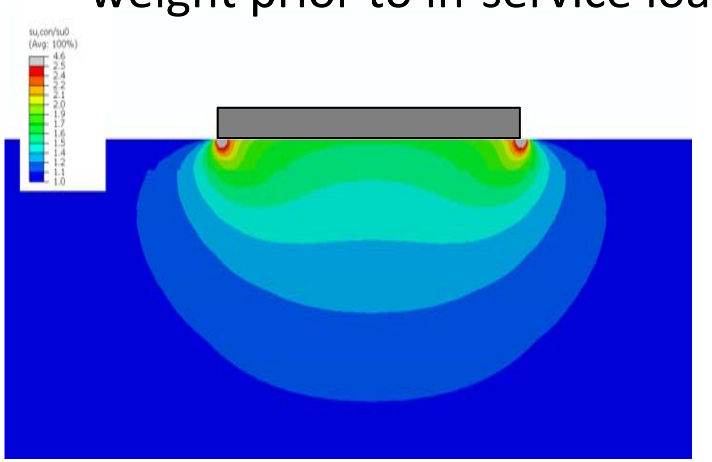
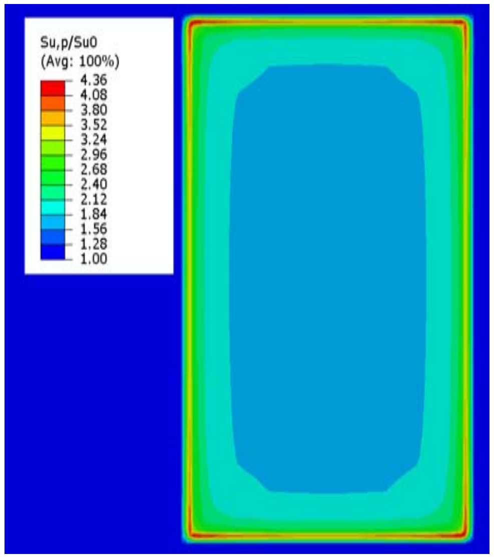
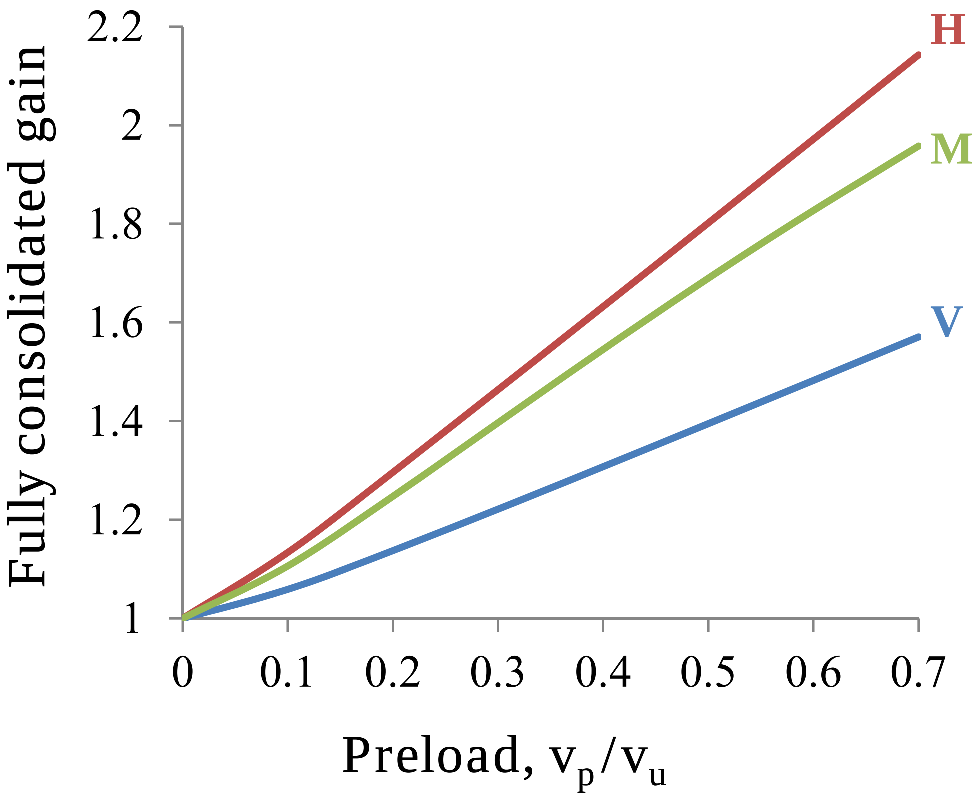
- Increase in in situ shear strength under foundation and structure self-weight prior to in-service loading.







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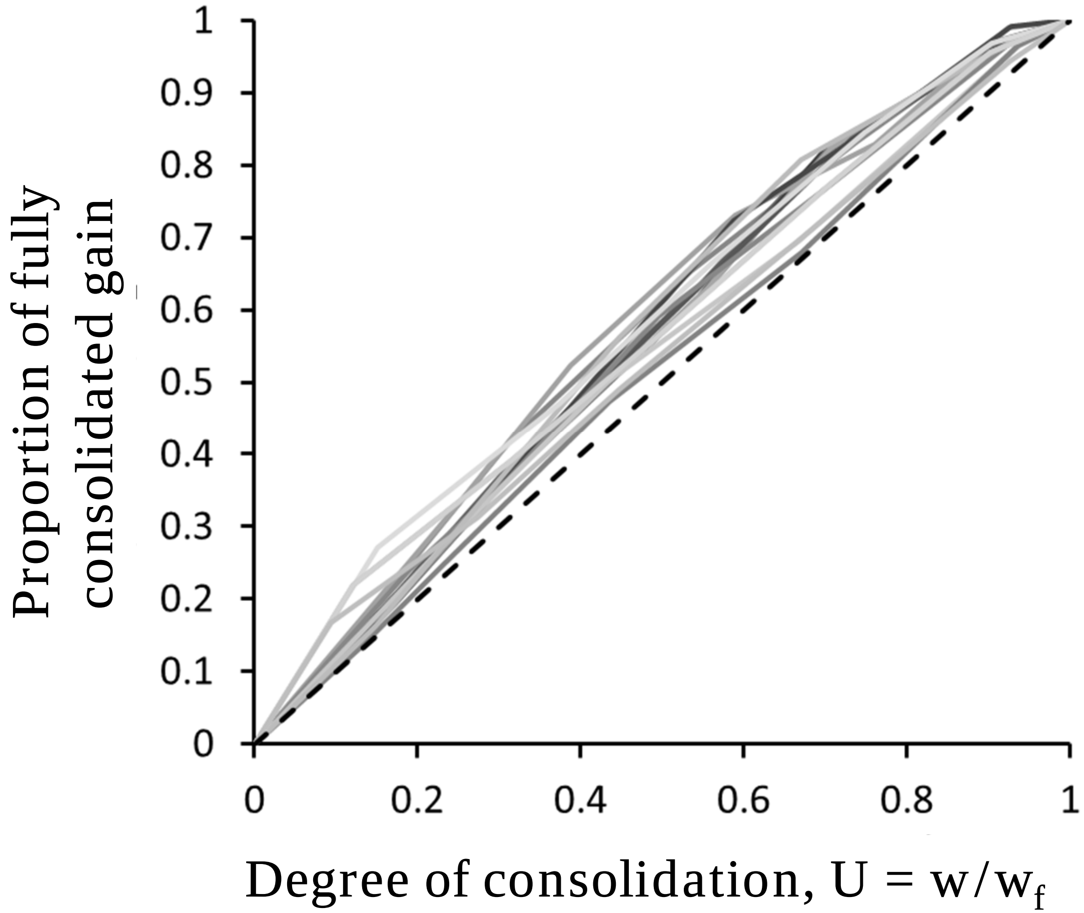
Consolidated shear strength

- Gain can be scaled linearly as a function of the degree of consolidation



Gourvenec et al, Géotechnique, 2014

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5. Mobile foundations

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- Federal funding for a 3 year project to develop a geotechnical design framework for mobile foundations.

INNOVATION
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Industry needs underpin pioneering research

BY LAUREN BARRETT

ARMED with federal funding and industry interest, a team of engineers from the University of Western Australia is looking to challenge traditional thinking that foundations for deep-sea oil and gas pipeline infrastructure must be stationary.

The research could improve the international competitiveness of Australia's energy sector, with hopes it will make the hard task of unlocking stranded reserves cheaper.

The research project, headed by Professor Susan Gourvenec, will take place at UWA's Centre for Offshore Foundation Systems.

The project is aiming to prove that it is possible to design mobile foundations as a safe and efficient way to support seabed infrastructure instead of the traditional stationary foundations.

While the idea may draw its fair share of sceptics, the advantages mobile foundations can deliver the oil and gas sector are too promising to ignore.

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Going mobile with offshore foundations *(Page 1 of 3)*

By Martin Kovacs, 20 Jan 2014

Foundations are traditionally thought of as stationary, providing support for structures such as homes and office buildings from underneath. In the offshore oil and gas industry they are used to support offshore facilities and subsea infrastructure from manifolds through to pipelines. However, new research from the University of Western Australia's (UWA) Centre for Offshore Foundation Systems (COFS) is challenging this paradigm.

Having recently secured federal funding for the research, COFS Professor Susan Gourvenec is seeking to create a design framework for mobile foundations to support deep-water subsea infrastructure.

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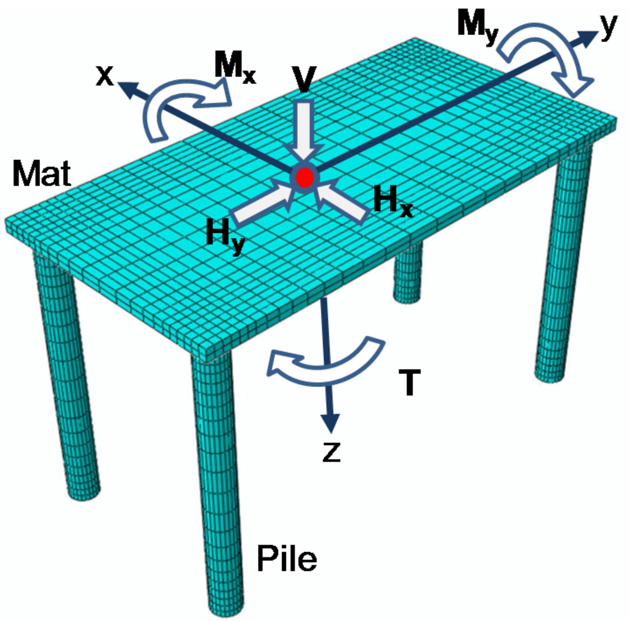
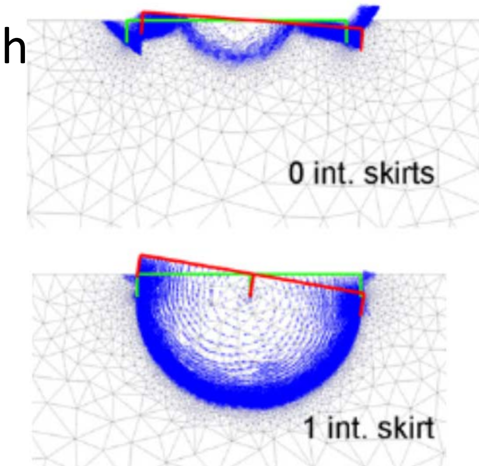
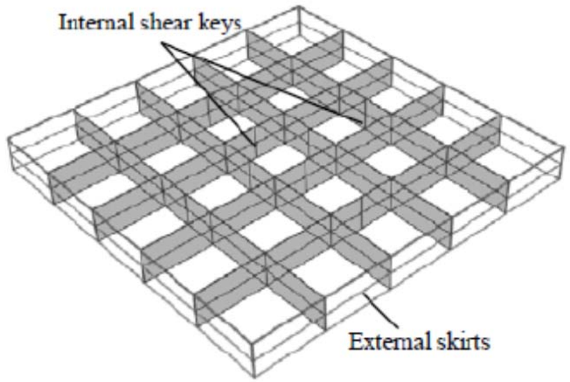
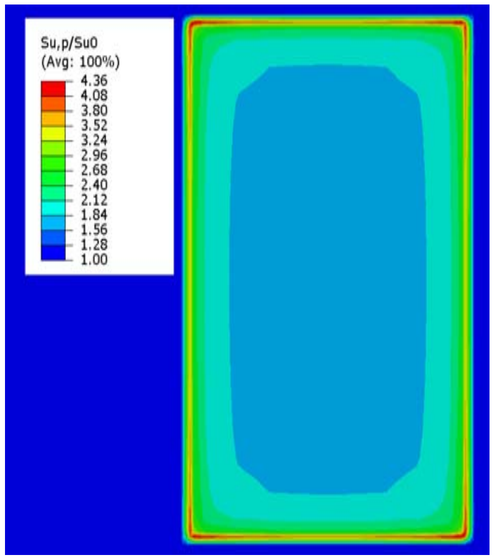
Toolbox for optimized design

1. 6 dof failure envelope design methodology and calculation spreadsheet
2. Pin piles – ‘hybrid subsea foundation’
3. Skirt spacing
4. Consolidated shear strength
5. Mobile foundations









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- Australian Research Council
- Our industry partners, in particular Subsea 7
- EMI for sponsoring this evening
- SUT for the invitation to talk

Thank you for your attention!

Please feel free to contact me:

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