Obsolescence of analytical methods in foundation design of big WTG

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BACKGROUND

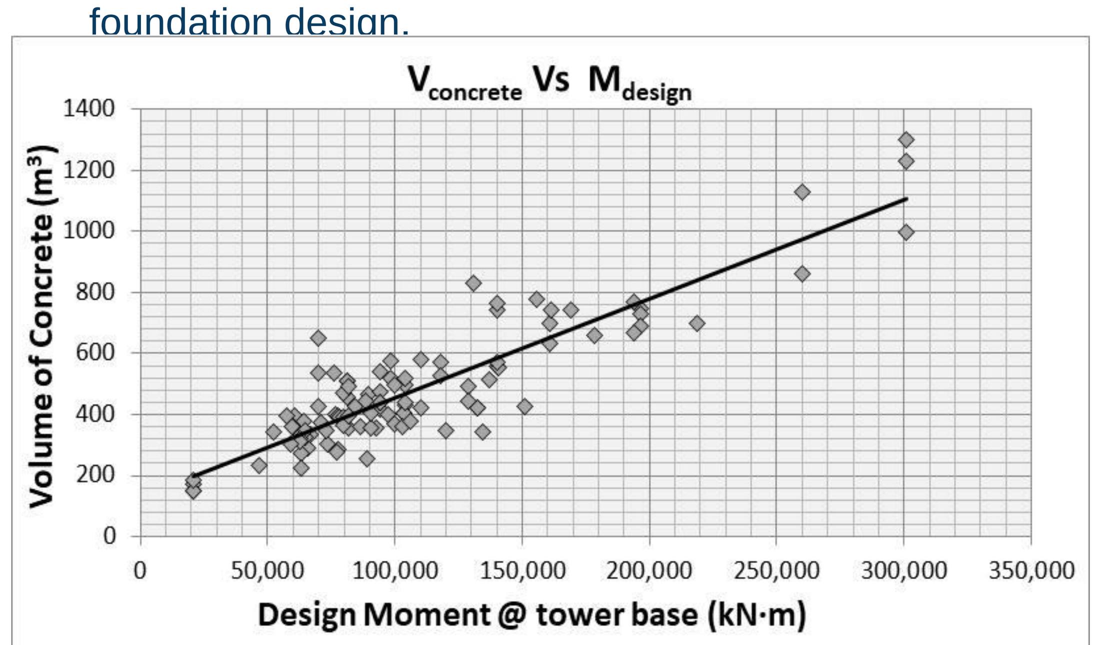
Bigger Turbines → Bigger Loads → Bigger Foundations

Rigid behaviour Vs. **Flexible behaviour**

With the current foundation volumes we are in the boundaries of the applicability of some analytical expressions widely used in foundation Geotechnical and Structural calculations, specially in early stages of design, as they assume the foundation to be a rigid body.

Two possible scenarios:

- Analytical expressions on the safe side → Overprice. Foundation volume overestimated.
- Analytical expressions under safety → Danger. Unsafe foundation design.



OBJECTIVE

Overcome limitations of analytical methods by **3D Finite Element Modelling**,

Point 1 – Structural 3D FEM analysis - No-GAP condition: Current analytical formulations lead to designs that are sometimes overestimated, sometimes not safe. Foundation geometry can be either optimized or made safe if FEM is used for preliminary calculations / tender phases.

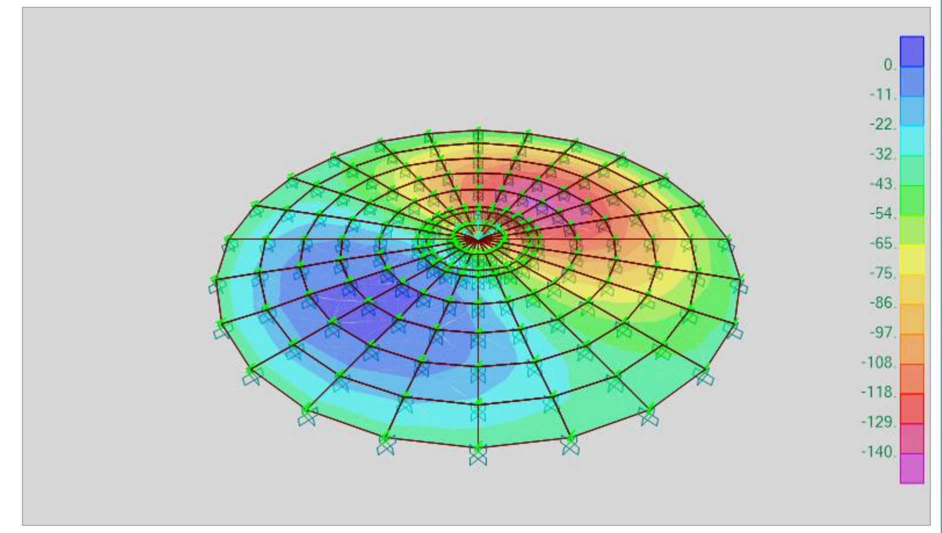
Point 2 – Geo 3D FEM analysis – Dynamic rotational stiffness: Current analytical formulations consider that foundations are completely rigid, but lighter solutions might be more flexible (larger diameters, ribbed and/or hollow foundations). Additionally, the FEM can be used for other geotechnical verifications or studies. Consequently, 3D FEM reduces the uncertainly providing more guarantees to companies in design solutions with costs reductions.

RESULTS

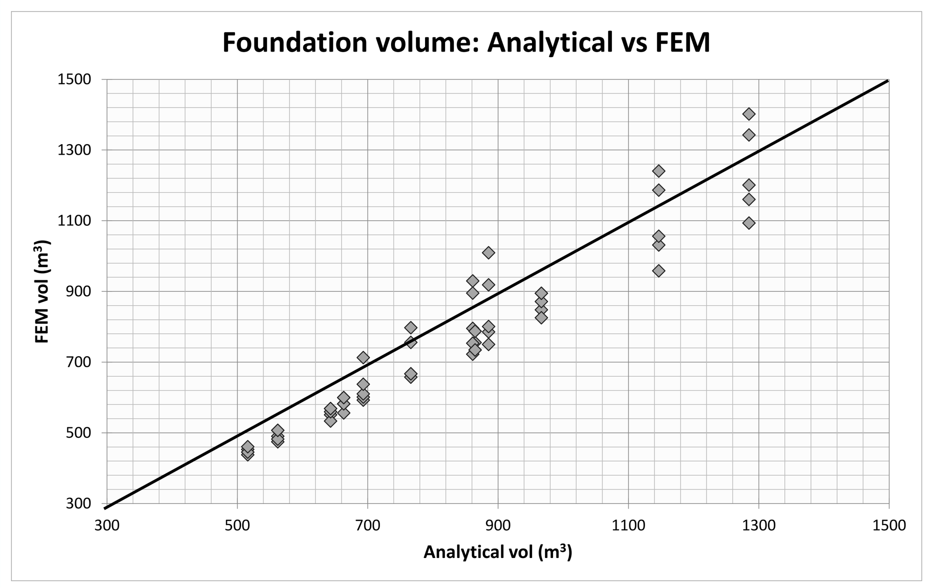
Point 1 – GEOMETRY AND NO-GAP CONDITION

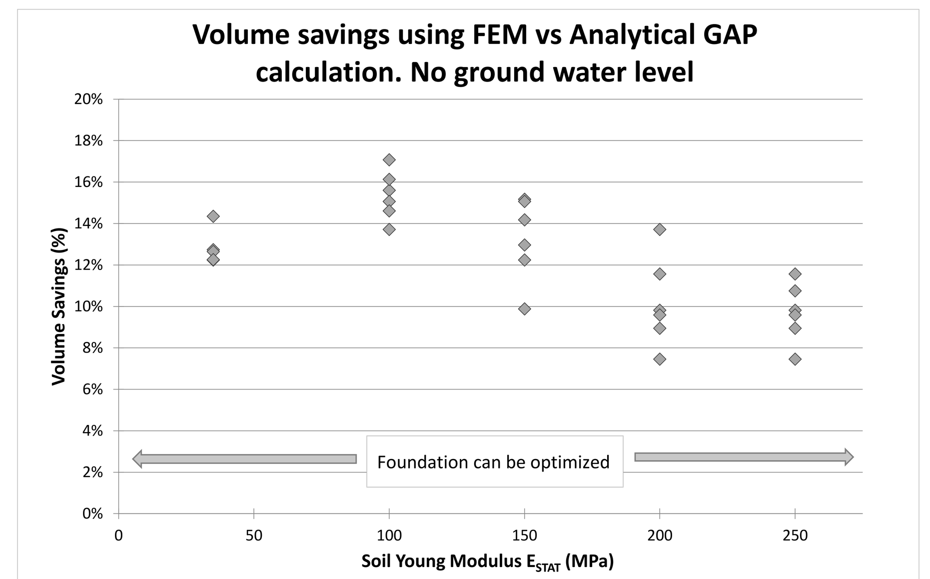
Foundation dimensions from GAP

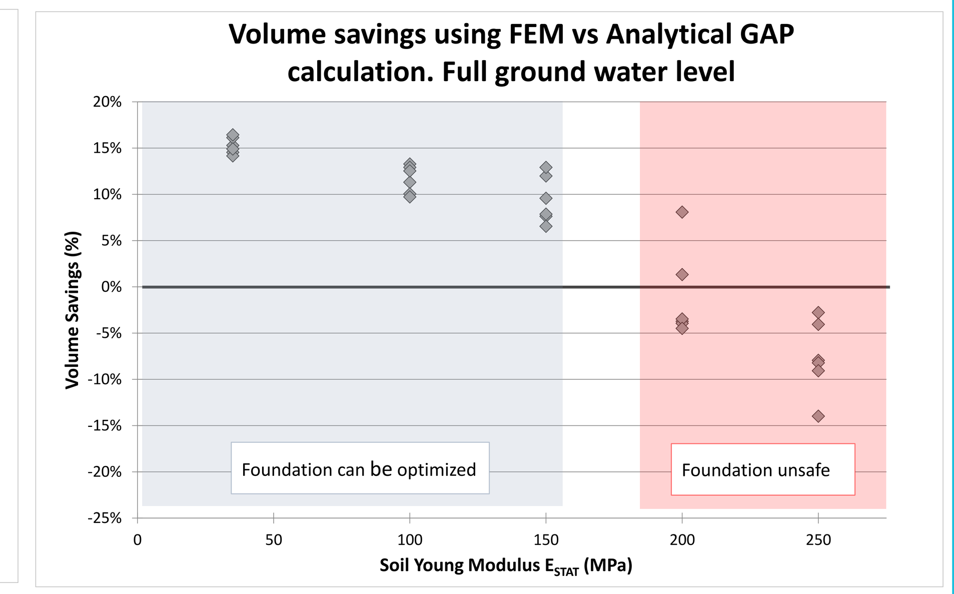
FEM ↔ Analytical: Foundation flexibility | Ground flexibility | Buoyancy effects



- With **no buoyancy effects**, volumes obtained with FEM < volumes obtained by analytical expressions, for every type of terrain underneath:
  → Cost savings using FEM in predesigns / Optimized design in early stages.
- With **buoyancy effects**, volumes obtained with FEM may be above or below those obtained by analytical expressions, depending on the stiffness of the ground→ **FEM analysis needed** for unsafe cases.
  → Analytical formulations are NOT VALID for big gravity foundations in rigid soils with buoyancy effects.
  → Set limits for necessary FEM modelling (safety) / optional FEM modelling (cost saving).

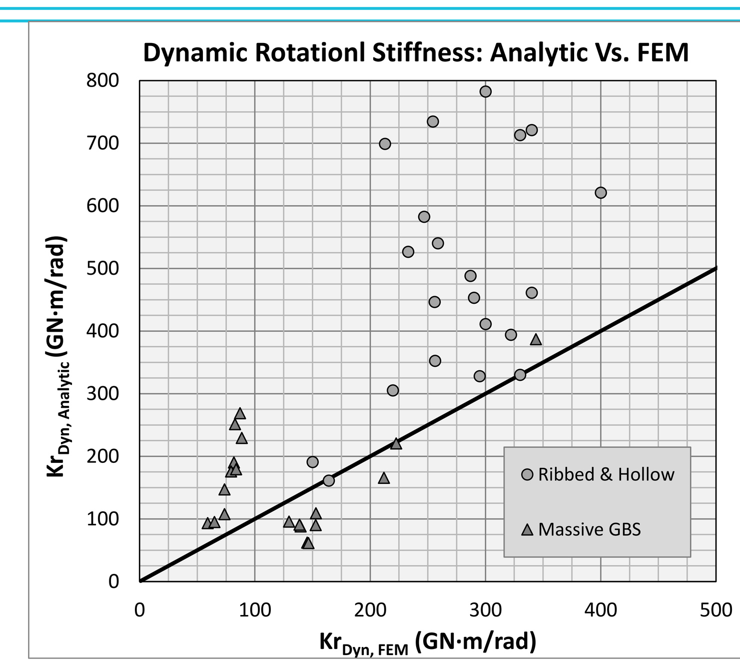


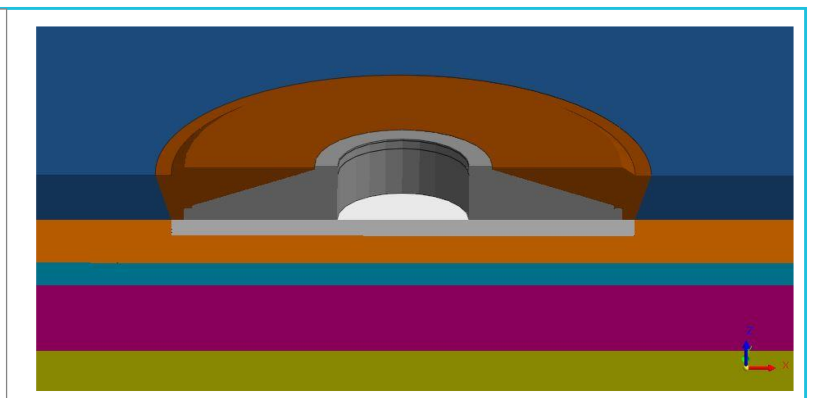


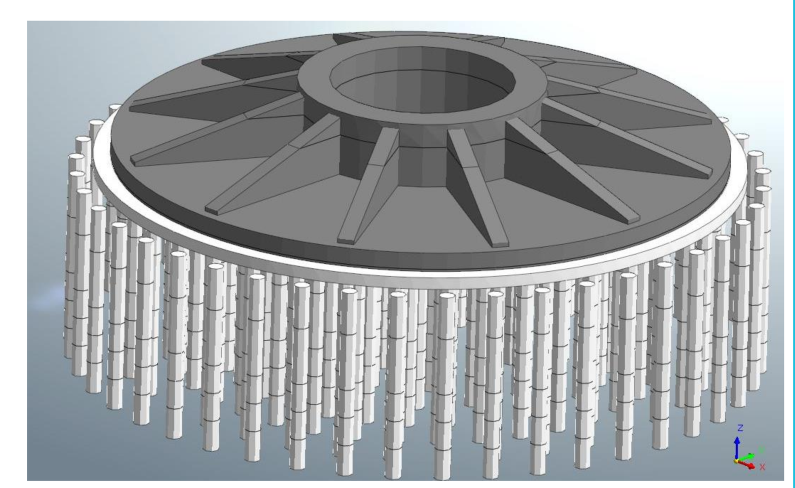


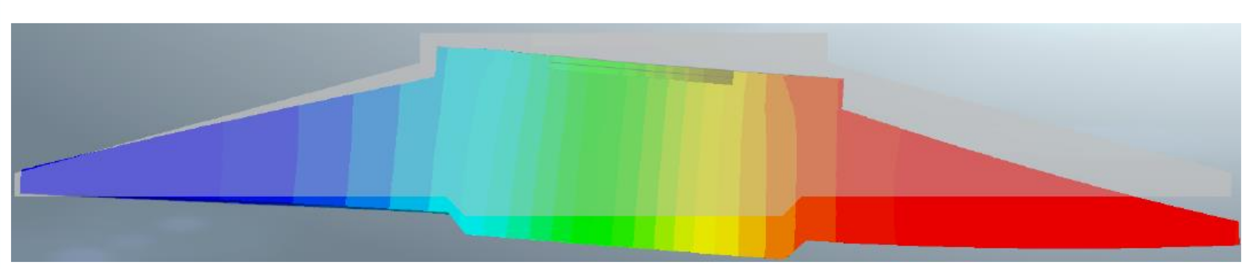
Point 2 – DYNAMIC ROTATIONAL STIFFNESS

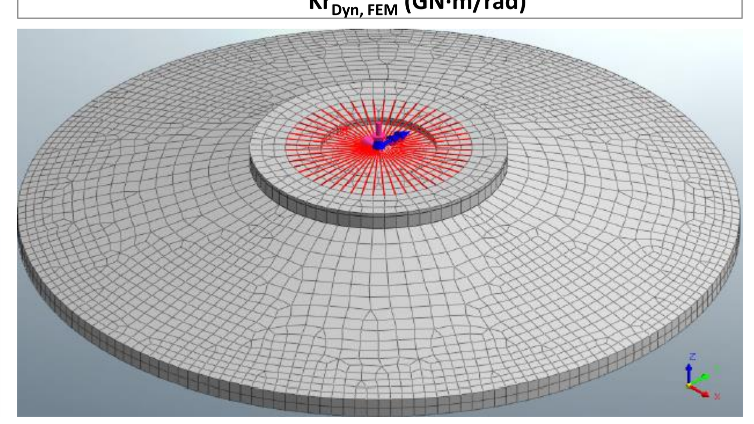
- With adequate ground data, 3D GEO FEM more accurate than analytical calculations for optimization.
- Massive Gravity Base Solution (GBS):
  → Values usually are lower than analytical estimations/ For large gravity foundations, the hypothesis of full rigidity NO LONGER valid.
  → Greater confidence to clients / Reduce uncertainties / Optimize foundation geometry / Avoid unnecessary soil improvements.
- Ribbed and Hollow foundations:
  → Analytical formulations are NOT VALID and overestimate the dynamic rotational stiffness.
- GBS with EPS (Expanded Polystyrene):
  → REAL INTERACTION Foundation-EPS-Ground/ Appropriate introduction of EPS parameters/ Real distribution of ground stresses.
- Ground improvements: soil replacement, Stone/ mortar columns, etc.
  → Avoid weighing geotechnical parameters which have very different stiffness/ lower uncertainty.
  → Optimize ground improvements/ Reduce costs.

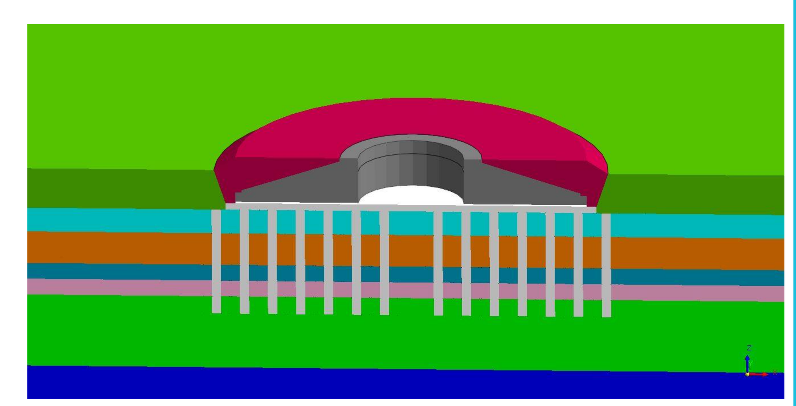




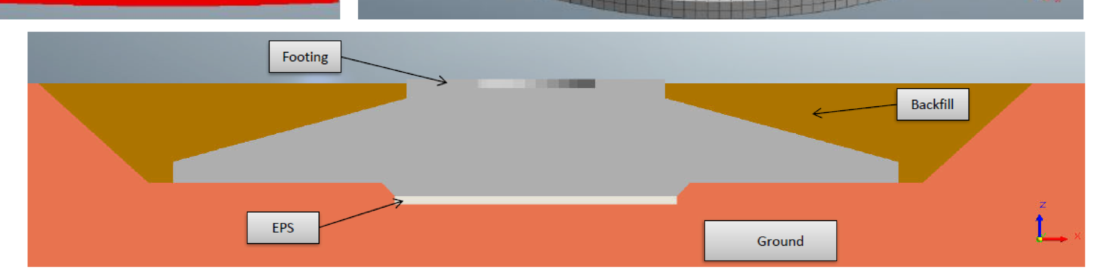








- Once FEM is done, **other geotechnical checks or studies can be carried out**: differential and total settlements, static rotational stiffness, dynamic horizontal stiffness, bearing capacity, slope stability, ground stresses, movements along the construction process, etc.



CONCLUSIONS

3D structural FE Modelling for GAP analysis provides:

→ Safe designs / Reduce uncertainties / Optimization of the foundation geometry / Cost savings / Confidence to clients

→Efficiency in design by routines and AI programming

3D GEO FE Modelling for Dynamic Rotational Stiffness provides:

→ Optimization of the foundation geometry/ Confidence to clients/ Reduce uncertainties / Avoid unnecessary improvements/ Cost savings

→Consideration of the flexibility of the foundation (big size, ribbed, hollow).

→Obtain the stiffness of the foundation-soil assembly, a value comparable to the minimum value required by the wind turbine specification

→ Incorporation of Ground improvements/ Modelling of highly layered soil conditions/ Solve Slope stability problems

→Study of other geotechnical verifications

ACKNOWLEDGEMENTS

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