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FINITE ELEMENT ANALYSIS OF SOIL BEHAVIOUR DURING CYCLIC LATERAL LOADING OF MONOPILES

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ABSTRACT

Monopiles used for offshore wind farm foundations are regularly subjected to cyclic lateral loading. The pile displacements as a result of this loading are transferred into the soil medium, inducing strains. Energy is also transmitted from the pile motion into the ground. Understanding the strain levels and energy dissipation is of growing importance because wind farm installations in different environments present new challenges. Finite element modelling can be used to aid the understanding of the soil response, which in the small strain region depends on many parameters. Improvements in constitutive models have allowed for these parameters to be accounted for in a geotechnical analysis. This research uses the finite element code ICFEP to investigate the effects of force amplitude, depth and pile diameter on displacements, damping ratio and deviatoric strain levels. A comparison is made between the 2D analyses and a parallel 3D model to validate these results, drawing upon any limitations of the former. This research also evaluates current industry practices used to relate pile displacements to equivalent strain levels, appraising the empirical relationship against data from the model. It then investigates how these strain levels may relate to the soil damping ratio.

MODEL INPUTS

Pile diameters of 0.76m and 2.0m are investigated. These dimensions are based on proposed installations at Cowden, UK (PISA AWG, 2014). The soil properties in Table 1 are based on this site. Load amplitudes ranging from 1kN to 100kN have been applied to these piles.

TABLE 1

Pile diameter (m)	Depth (m)	OCR (-)	u (kPa)	σ_z (kPa)	$\sigma_x = \sigma_y$ (kPa)
0.76	1.0	49.2	0.00	21.2	31.8
2.0	2.6	19.6	15.2	39.9	59.8
0.76	3.0	13.7	19.6	44.5	66.8
2.0	7.8	4.87	55.8	109.5	120.4

FIGURE 1

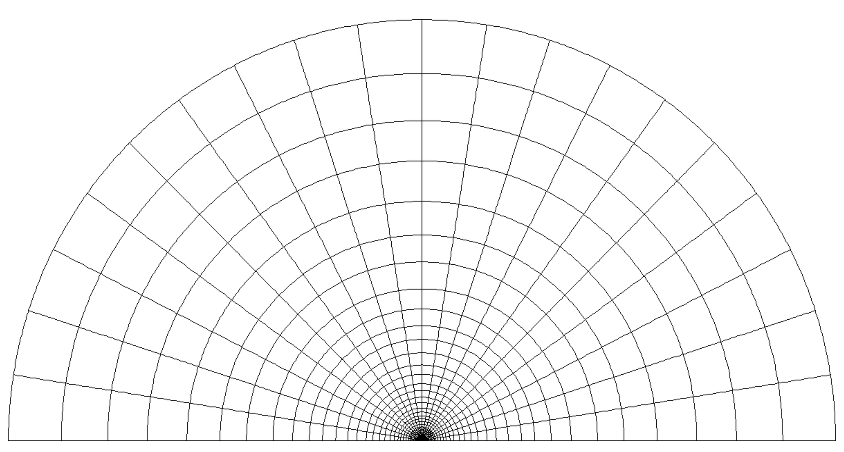

Figure 1 shows the 2D finite element mesh used to represent the scenario. A total of 748 elements including interface elements have been used. Only half a pile has been modelled since the loading is unidirectional. The circumferential boundary is at a distance of 30m from the pile centre.

SOIL BEHAVIOUR

The FE model makes use of a Modified Cam-Clay Model with a Hvorslev surface to describe the critical state envelope. A nonlinear elastic model is used in conjunction to describe the soil behaviour within the small strain region. The model has been adapted for cyclic loading.

FIGURE 2

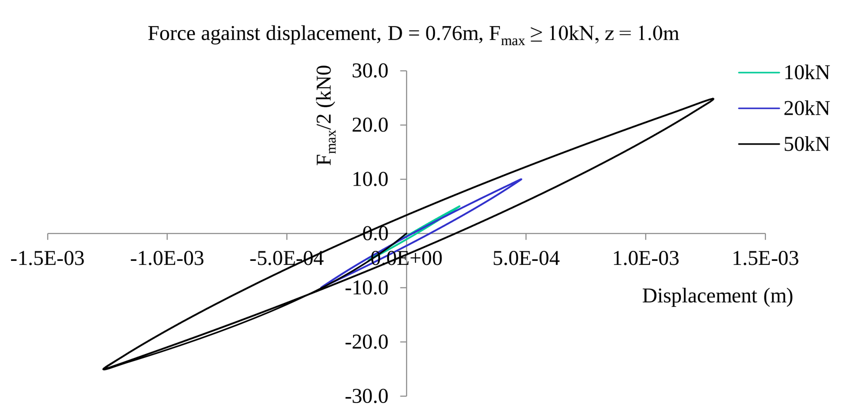

Figure 2 shows pile displacement increasing with force amplitude. This also results in an increase in strains in the soil. The diagram also shows damping ratio getting bigger with larger loads, as the nonlinear loading loops increase in size, resulting in more energy losses (Taborda, 2011).

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FIGURE 3

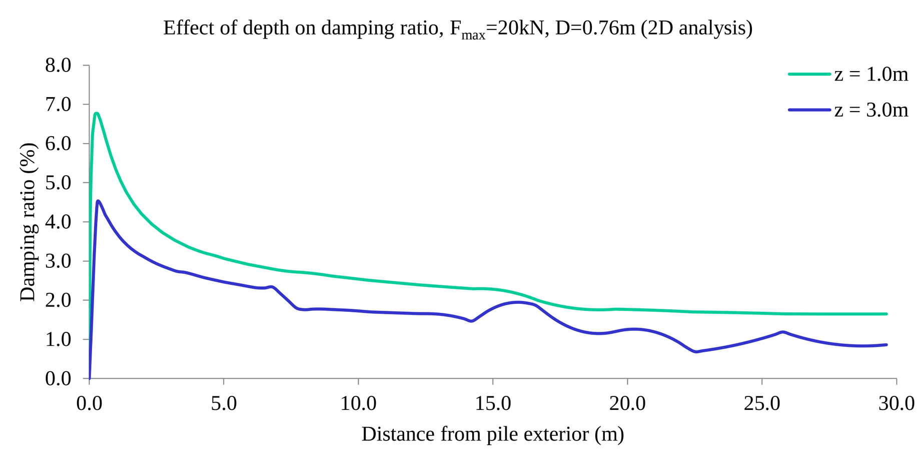

Figure 3 shows damping ratio reducing with depth for a given load case. This is because the soil has a stiffer response with depth, attributed to the larger confining pressure (Darendeli, 2001), resulting in smaller displacements and therefore lower strains and damping ratios.

FIGURE 4

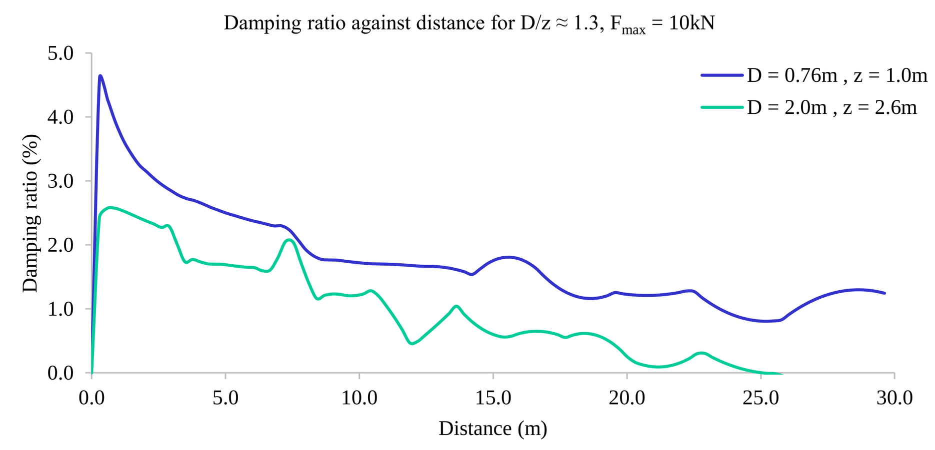

Figure 4 compares the damping ratio for two different pile sizes with the same diameter-depth ratio. The smaller values for the larger pile can be attributed to the larger circumference and lower stress applied around the pile.

2D & 3D ANALYSIS

The 3D analysis considers the 0.76m diameter pile. Loads are applied at the mudline unlike in the 2D analysis, where the load is applied at the depth considered. Vertical displacements can occur at the mudline, which would violate the 2D plane strain condition.

FIGURE 5

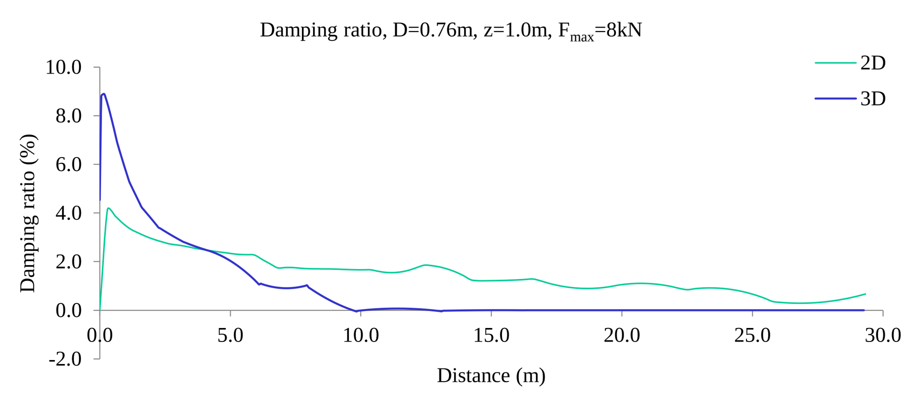

Figure 5 shows a larger peak damping ratio for the 3D analysis than the 2D analysis. This is a result of larger displacements in the 3D results, which can be attributed to less restraints in the vertical direction and the effects of rotation.

API STRAIN-DISPLACEMENT RELATIONSHIP

Guidance is available from the API (2000) to relate forces and pile displacements using strains from triaxial compression tests. In this analysis, the displacement for a load case is converted into the equivalent strain. The damping ratio is then found at the location of this strain level in the soil using ICFEP. This damping ratio is compared against the damping ratio found for the pile using work energy principles.

FIGURE 6

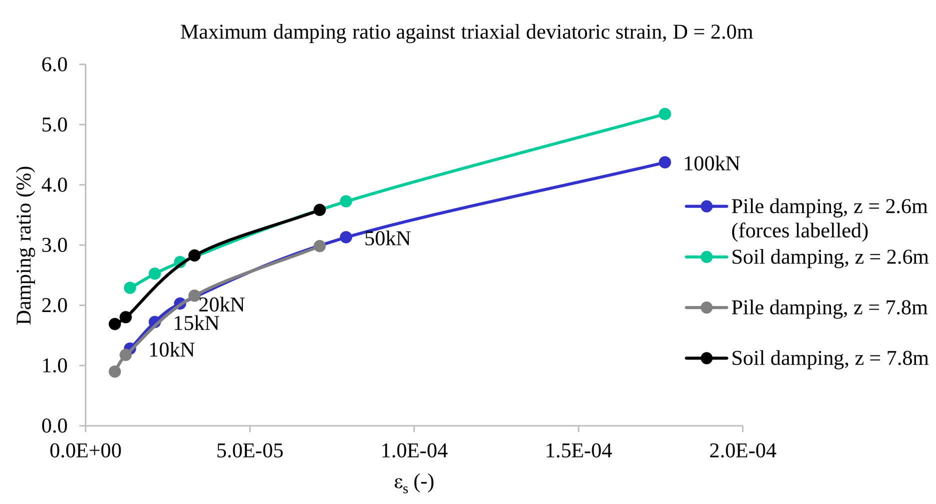

Figure 6 demonstrates that the damping in the soil is always higher than the pile damping ratio for the same strain level. What it does not show is the underestimate of maximum soil damping ratio. The API empirical relationship does not find the maximum strain level in the soil.

CONCLUSION

An increase in force amplitude results in an expected rise in displacements, strains and damping ratios. An increase in pile diameter conversely reduces these values. The 3D analysis gives a larger estimate than the 2D, possibly because the pile and soil motions are different. The API relationship predicts strain levels lower than those from ICFEP, which corresponds to non-conservative damping ratios.

REFERENCES

American Petroleum Institute. (2000) API RP 2A-WSD. Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms - Working Stress Design. API. Washington.

Darendeli, M. B. (2001) Development of a new family of normalized modulus reduction and material damping curves. PhD Thesis. University of Texas, Austin.

PISA Academic Work Group. (2014) PISA Project: Draft Design Methodology. DONG Energy.

Taborda, D. (2011) Development of constitutive models for application in soil dynamics. PhD Thesis. Imperial College London.