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ABSTRACTS

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INDEX

Influence of modelling hollow piles with solid piles on the dynamic behaviour of pile foundations

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1. Introduction – The aim of this work is to assess the accuracy of the results obtained for the dynamic response of pile foundations when modelling hollow piles with equivalent solid piles. In order to establish this equivalence, a simplified model based on the Winkler approach for embedded beams is used to identify the main dimensionless parameters characterizing the dynamic behaviour of a single pile when considering soil-structure interaction. This type of models has been previously used by other authors to determine impedance functions and kinematic interaction factors of pile foundations (*e.g.* [1]).

2. Methodology – The use of the simplified model based on the Winkler approach for embedded beams [2] leads to the identification of the dimensionless parameters covering the main features of the problem. These are: (1) ratio of the Young's module of an equivalent solid pile that could model the dynamic behaviour of the actual hollow pile to that corresponding to the soil $\mathrm{E_p}/E_s$; (2) pile slenderness ratio L/d; (3) ratio of the pile length to the radius of gyration of the actual pile cross section $L/\tilde{\iota}_p$ (being $\tilde{\iota}_p^2 = \tilde{I}_p/\tilde{A}_p$ the ratio of the rotational inertia to the area of the actual pile cross section); (4) ratio of the mass density of equivalent solid pile to that corresponding to the soil ρ_p/ρ_s; (5) dimensionless excitation frequency $a_o = \omega d/c_s$ (being ω the excitation circular frequency, c_s the speed of propagation of shear waves in the halfspace); (6) Poisson's ratio ν_s; (7) pile spacing ratio s/d; and (8) pile rake angle in the direction of excitation θ. The parameter γ, in Image 1, represents the ratio of the internal to the external diameter of the pile cross section.

Image 1. Piles cross-section

The values of the properties assigned to the solid circular cross section in order to model the actual annular cross section, E_p and ρ_p, vary with γ according to equations (1) and (2), where $\tilde{E}_p$ and $\tilde{\rho}_p$ are the pile material Young's module and mass density respectively.

$$E_p = \tilde{E}_p \frac{\tilde{I}_p}{I_p} = \tilde{E}_p(1-\gamma^4) \quad (1)$$

$$\rho_p = \tilde{\rho}_p \frac{\tilde{A}_p}{A_p} = \tilde{\rho}_p(1-\gamma^2) \quad (2)$$

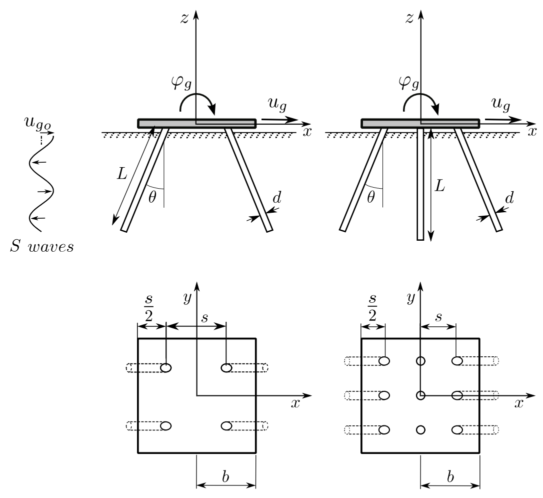

Image 2. Pile foundation geometry

For the purpose of assessing the accuracy of modelling a hollow pile by assuming a solid circular cross section, the dynamic response of several pile group configurations has been computed through a boundary element (BEM)-finite element (FEM) coupling model [3]. Piles are modelled directly using FEM, while soil is modelled using BEM.

3. Results – The dynamic response of several 2 x 2 and 3 x 3 pile group configurations containing vertical piles ($\theta = 0^o$) and piles inclined in the direction of excitation, with three different rake angles $\theta = 10^o, 20^o$ and 30^o, are analysed. Pile groups are considered to be subjected to vertically incident plane S waves. All configurations follow the pattern depicted in Image 2. It is assumed that $E_p/E_s = 10^3$; $L/d = 15$; ρ_s/ρ_p=0.7; $\xi_s = 0.05$ and $\nu_s = 0.4$.

The accuracy of modelling a hollow pile as a solid one is assessed through comparisons with the results obtained when considering the actual annular geometry of the pile cross section in each case. Table I lists the properties corresponding to each annular section under investigation while Table II provides those corresponding to the solid model in each case.

Table I. Actual annular cross-section geometry and material properties

γ	$\tilde{A}_p$	$\tilde{I}_p$	$L/\tilde{i}_p$	$\tilde{E}_p$	E_s	$\tilde{\rho}_p$	ρ_s
0.00	3.1416	0.7854	60.00	2,800	2.800	1.000	0.700
0.50	2.3562	0.7363	53.67	2,800	2.625	1.000	0.525
0.80	1.1310	0.4637	46.85	2,800	1.653	1.000	0.252
0.90	0.5969	0.2701	44.60	2,800	0.962	1.000	0.133
0.95	0.3063	0.1457	43.50	2,800	0.519	1.000	0.068

Table II. Model solid circular cross-section geometry and equivalent material properties

γ	A_p	I_p	$L/\tilde{i}_p$	E_p	E_s	ρ_p	ρ_s
0.00	3.1416	0.7854	60.00	$2.800 \cdot 10^3$	2.800	1.000	0.700
0.50	3.1416	0.7854	60.00	$2.625 \cdot 10^3$	2.625	0.750	0.525
0.80	3.1416	0.7854	60.00	$1.653 \cdot 10^3$	1.653	0.360	0.252
0.90	3.1416	0.7854	60.00	$0.962 \cdot 10^3$	0.962	0.190	0.133
0.95	3.1416	0.7854	60.00	$0.519 \cdot 10^3$	0.519	0.098	0.068

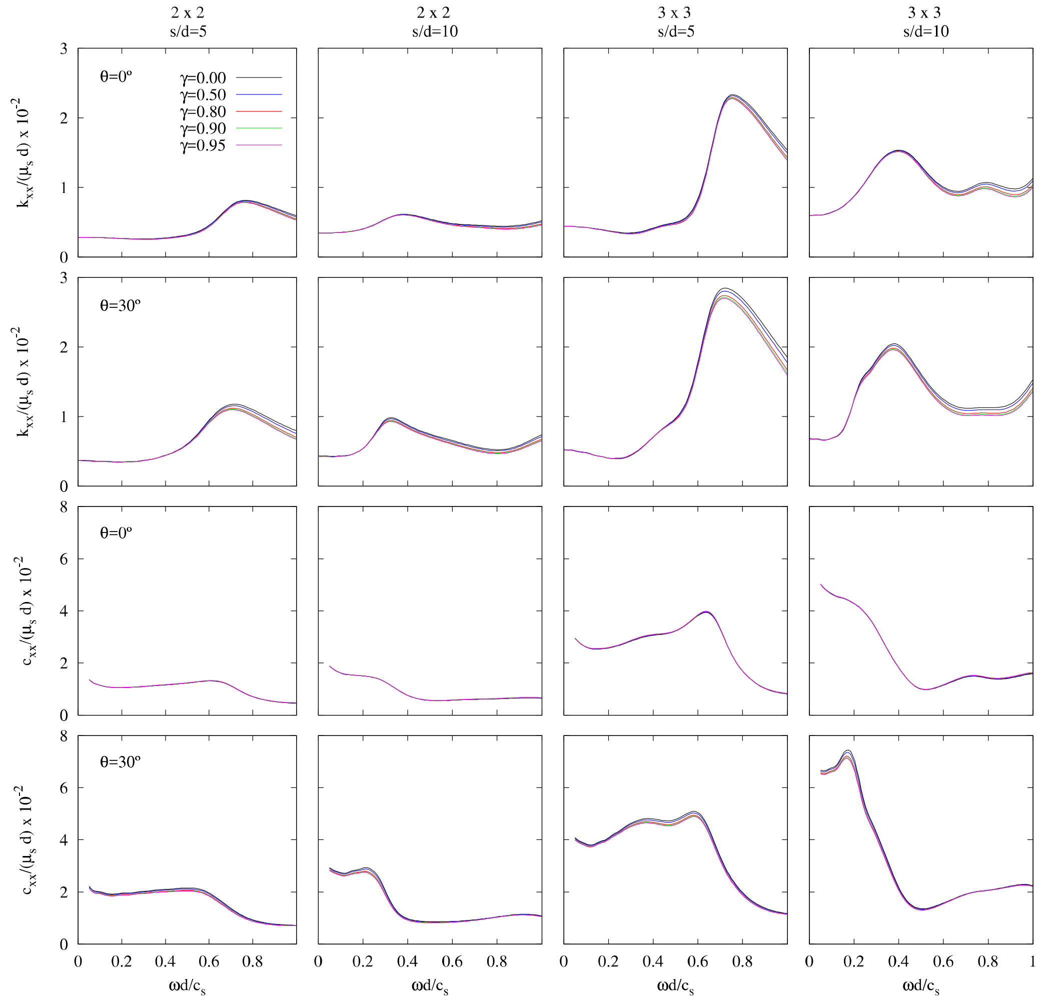

Image 3. Influence of pile cross-section geometry on the horizontal impedances of different 2 x 2 and 3 x 3 pile groups with vertical ($\theta = 0^o$) or inclined elements ($\theta = 30^o$).

Images 3 to 5 depict impedance functions corresponding to the horizontal, rocking and cross-coupled horizontal-rocking vibration modes, respectively. Although four different rake angles are considered in this study, aiming at providing the reader with concise information that can be easily interpreted, only those results corresponding to the rake angles $\theta = 0^o$ (vertical piles) and $\theta = 30^o$ are shown herein to illustrate the conclusions drawn from this analysis.

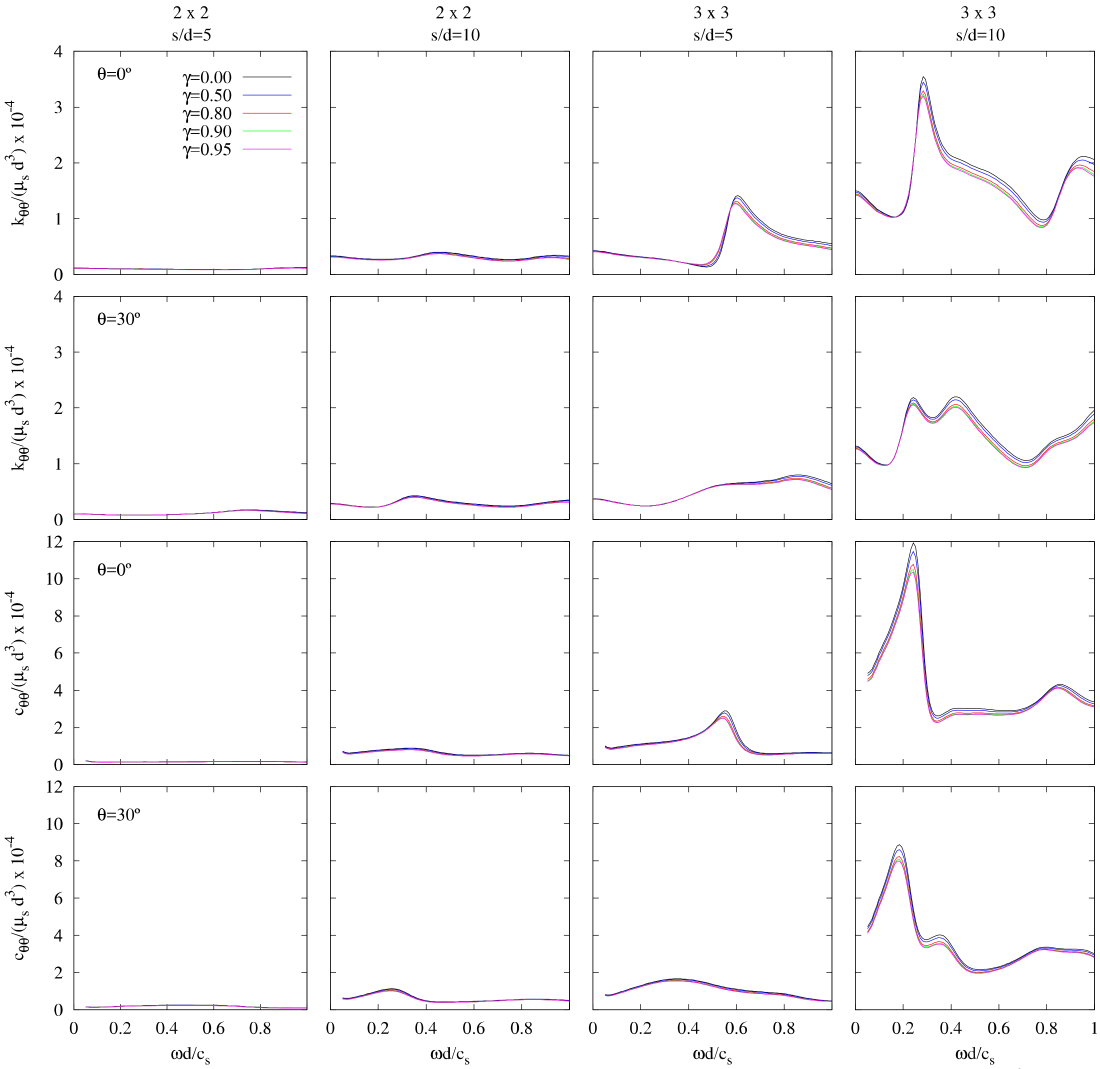

Image 4. Influence of pile cross-section geometry on the rocking impedances of different 2 x 2 and 3 x 3 pile groups with vertical ($\theta = 0^o$) or inclined elements ($\theta = 30^o$).

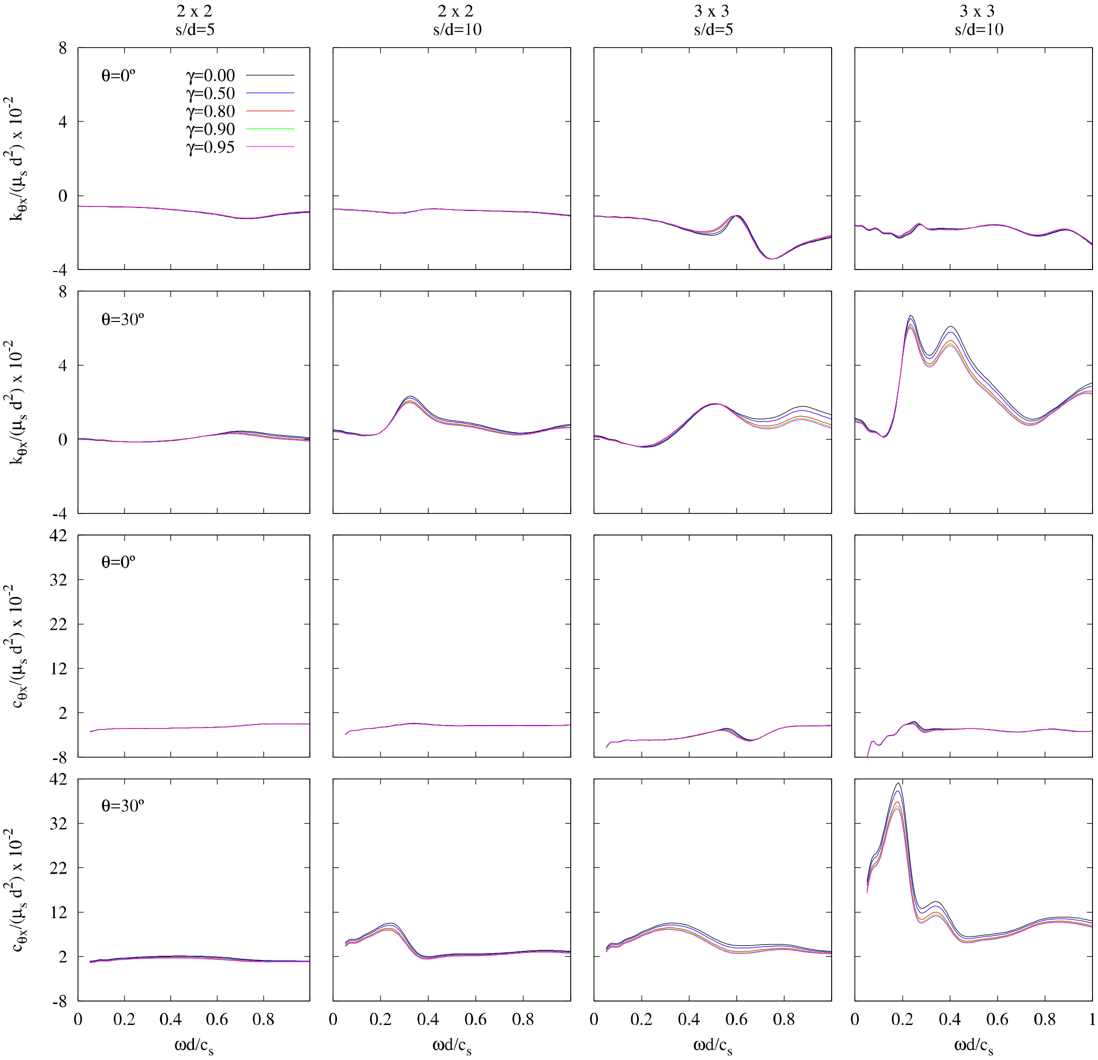

Image 5. Influence of pile cross-section geometry on the horizontal-rocking cross-coupled impedances of different 2 x 2 and 3 x 3 pile groups with vertical ($\theta = 0^o$) or inclined elements ($\theta = 30^o$).

Images 6 to 7 show, respectively, translational and rotational kinematic interaction factors for all the pile group configurations under investigation. In these images, the first and the third row present results corresponding to vertical pile groups, while the second and the fourth row correspond to pile groups including battered elements.

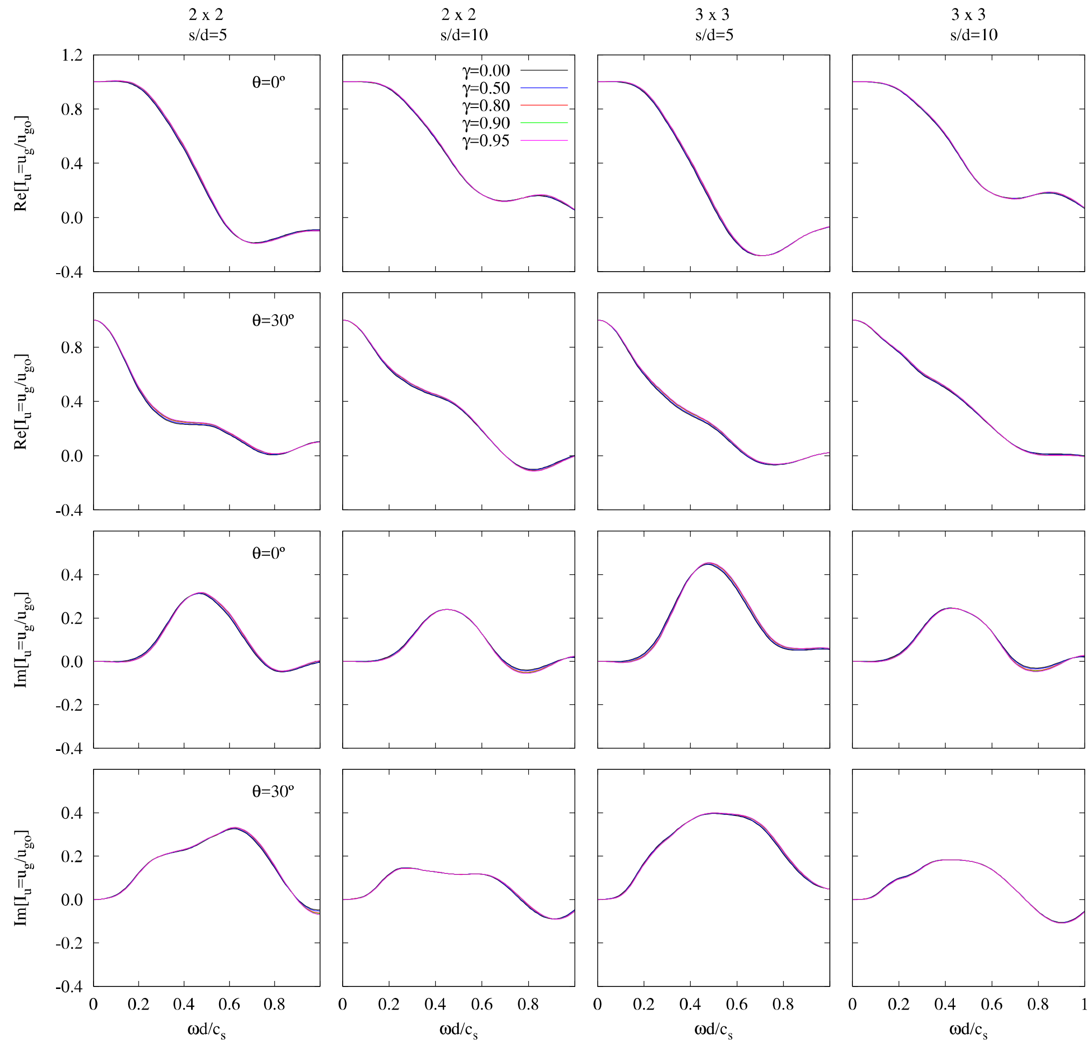

Image 6. Influence of pile cross-section geometry on the translational kinematic interaction factor of different 2 x 2 and 3 x 3 pile groups with vertical ($\theta = 0^o$) or inclined elements ($\theta = 30^o$).

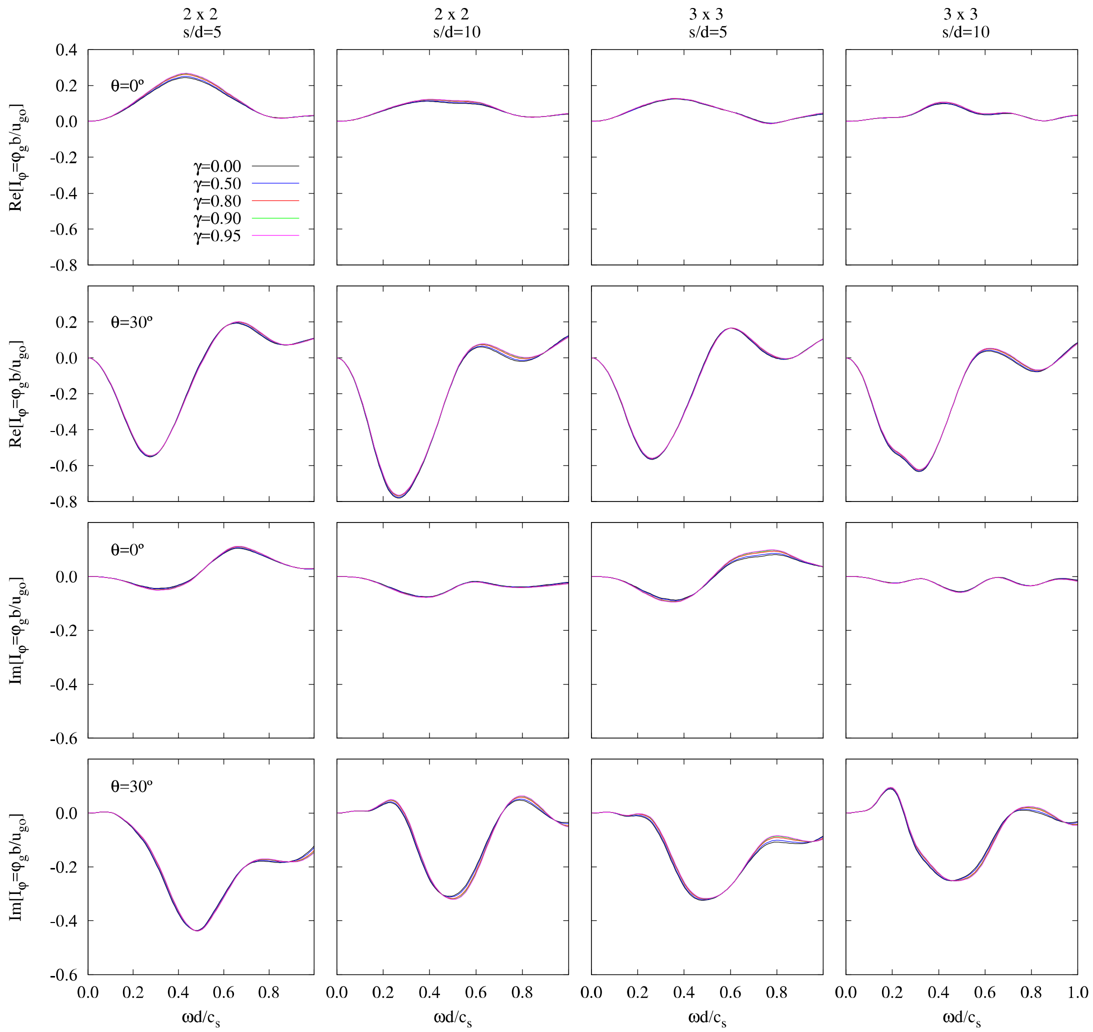

Image 7. Influence of pile cross-section geometry on the rotational kinematic interaction factor of different 2 x 2 and 3 x 3 pile groups with vertical ($\theta = 0^o$) or inclined elements ($\theta = 30^o$).

4. Conclusions – The variation of the ratio between the internal and the external diameter of the pile section γ does not yield great differences in terms of impedances, which implies that modelling the annular cross-section of piles as a solid cross-section leads to results accurate enough to represent the stiffness and damping of the soil-foundation system. However, it is found that modelling piles of annular cross-section by solid piles yields less accurate results as the rake angle increases. Moreover, no major differences are observed in the kinematic interaction factors obtained for different values of γ.

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