



ROCKING FOUNDATIONS ON UNATTACHED PILES

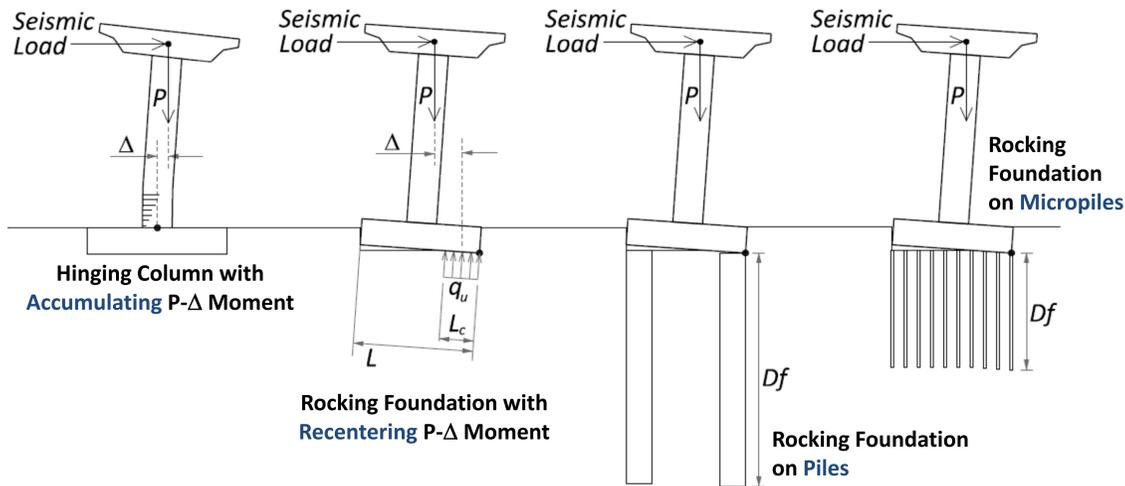
PEER Transportation Systems Research Program

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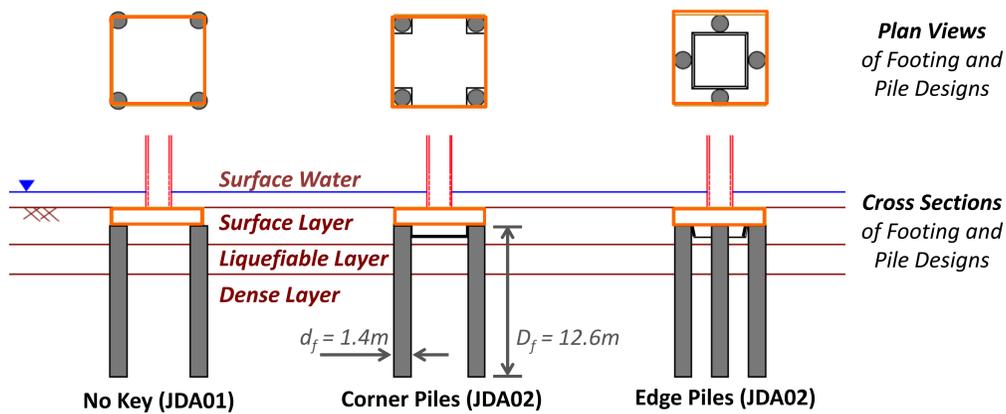
Introduction

Recent research has shown that rocking foundations on competent soils can reduce seismic ductility demand on bridge columns and improve bridge performance. The rocking mechanism acts as a self-centering isolation mechanism and permanent deformations are likely to be limited. This work aims at **defining situations and soil conditions where rocking foundations are not generally acceptable**, in addition to the applicability of using **deep soil foundation improvement** for rocking foundations through use of **unattached piles**.



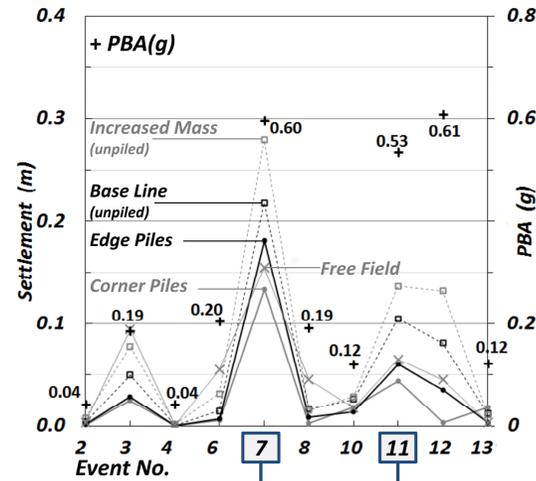
Centrifuge Modeling

Two centrifuge tests (JDA01 & JDA02) examined similar SDOF model structures representing a deck mass-column-footing system on fully saturated sand with a liquefiable layer and various unattached deep foundation pile designs (**shown below**).



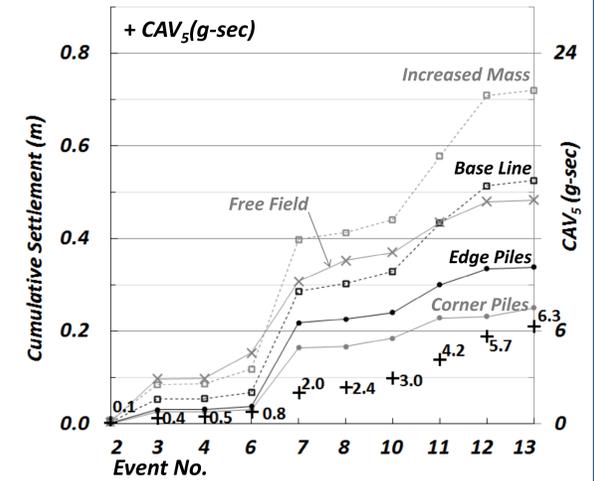
The No Key design of JDA01 did not prevent lateral sliding and eventual unseating of the footings from the piles occurred, resulting in detrimental residual rotations. The key designs of JDA02 were implemented to reduce lateral sliding while still allowing the foundation to rock, re-center, and control settlements.

JDA02 Settlements



Cumulative Footing Settlement

The **right** plot shows the residual cumulative settlement through each event. The Cumulative Average Velocity (CAV_5) is plotted on the second y-axis. This shows the general trend of reduced settlements with piled footings versus the free field and unpiled footings through testing.

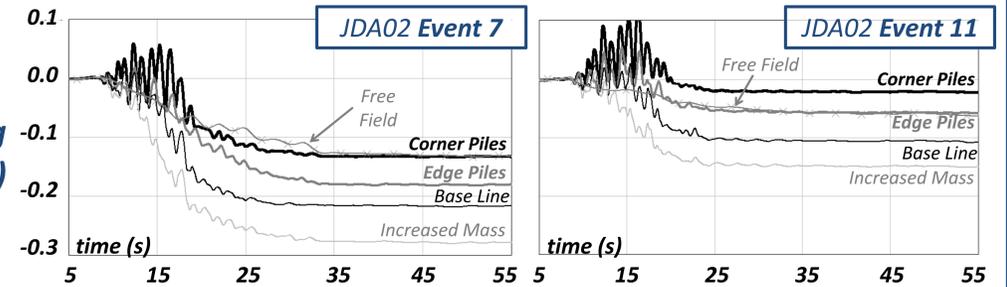


Footing Settlement per Event

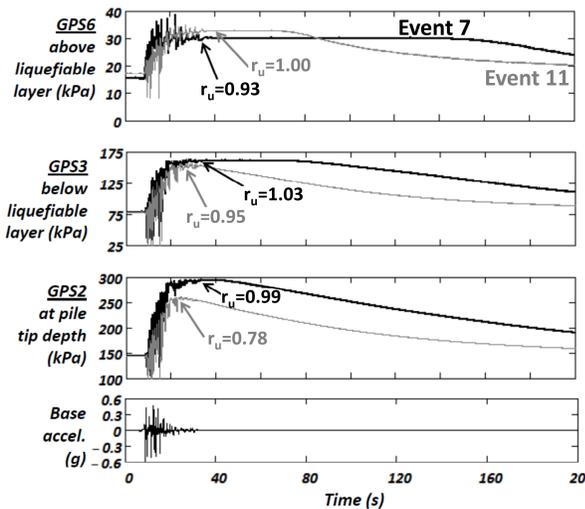
The **left** plot shows the residual settlements for each event with the Peak Base Acceleration (PBA) plotted on the second y-axis. Less settlement is attained after sequential strong shaking.

Event Comparison

↓
Footing Settlement (m)



Excess Pore Pressure



Settlement Factor of Safety

The **left** plot shows a decrease in excess pore pressure ratio ($r_u = \Delta u / \sigma'_v$) at pile depth between the two strong events, while the settlement time histories plotted **above** show a reduction in settlement for the piled footings. This response can be captured by altering the bearing capacity factor of safety for piles (FS_{vp}) by a reduction factor to account for deep liquefaction potential (FS_{vpru}). These results are tabulated **below**.

	Set. (m)		r_u	FS_{vp}		FS_{vpru}	
	Edge Piles	Corner Piles		Edge Piles	Corner Piles	Edge Piles	Corner Piles
Event 7	0.18	0.13	0.99	3.2	6.41	0.00	0.00
Event 11	0.06	0.04	0.78	3.2	6.41	0.70	1.41

N_{pile} = maximum number of piles loaded during rocking ($N_{pile} = 1$ for Edge Piles, $N_{pile} = 2$ for Corner Piles)

$$FS_{vp} = \frac{N_{pile} \cdot Q_{ult}}{Q_{app}}$$

$$FS_{vpru} = \frac{N_{pile} \cdot Q_{ult}}{Q_{app}} \cdot (1 - r_u)$$

Conclusions

- 1) The details of the lateral connection between the rocking footing and unattached piles are important.
- 2) It was found that if the bearing capacity of a single pile, reduced to account for reductions in effective stress due to liquefaction, is greater than the maximum load during rocking, that settlements will be limited.

Acknowledgements

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