



Seismic Analysis on Deep Water Bridge Piers Considering Water-Structure Interaction

PEER Transportation Systems Research Program

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Background

With the development of transportation, numerous large-scale bridges have been built in recent years. These bridges are often constructed in deep water, which are unfortunately located in the earthquake hazard zones in China.

When an earthquake occurs, the bridge piers oscillate in water, inducing the fluid forces on the piers. The seismic response—including displacement and acceleration at the top of the pier, and the shear force and moment at the top of the pier—can be amplified to some degree.



Miaoziping deep-water bridge

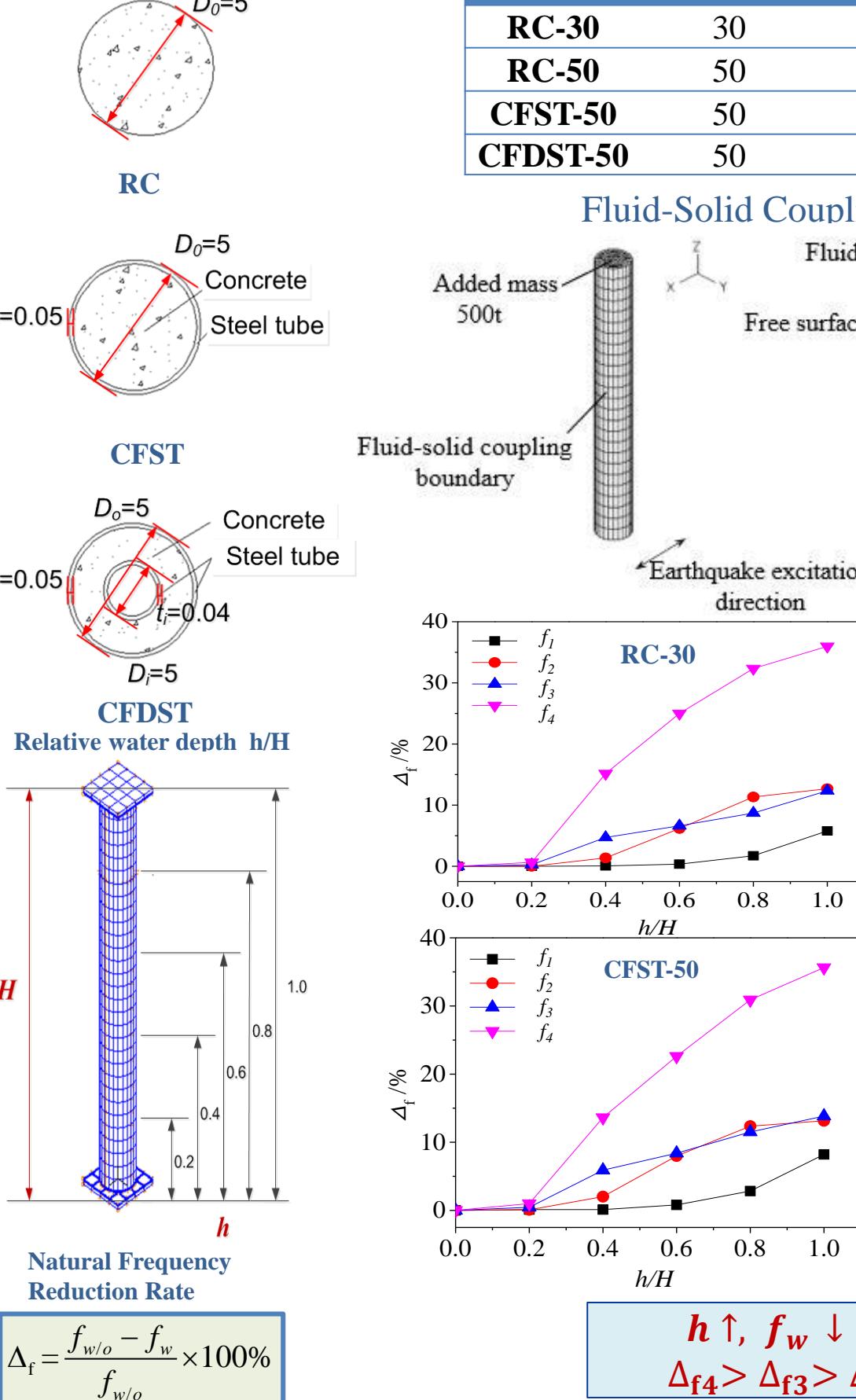
Beijing South Station Elevated Bridge

Under earthquake excitation, traditional reinforced concrete (RC) piers incline to have brittle failure, which is hard to repair; while concrete filled steel tubular (CFST) piers, due to their high bearing capacity and ductility, have gradually been applied in bridge projects, which is of great significance to improve the safety of bridges.

In this paper, seismic response and seismic performance of deep-water composite bridge piers are studied, and the applicability of simplified analyzing method for water-pier interaction is evaluated.

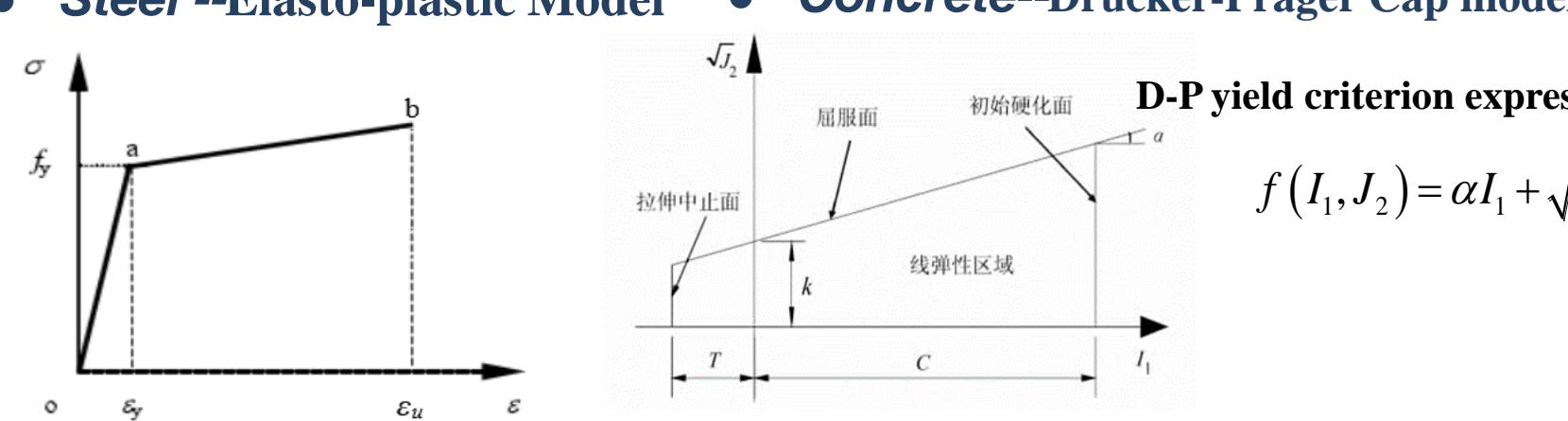
Dynamic Analysis

Modal Analysis

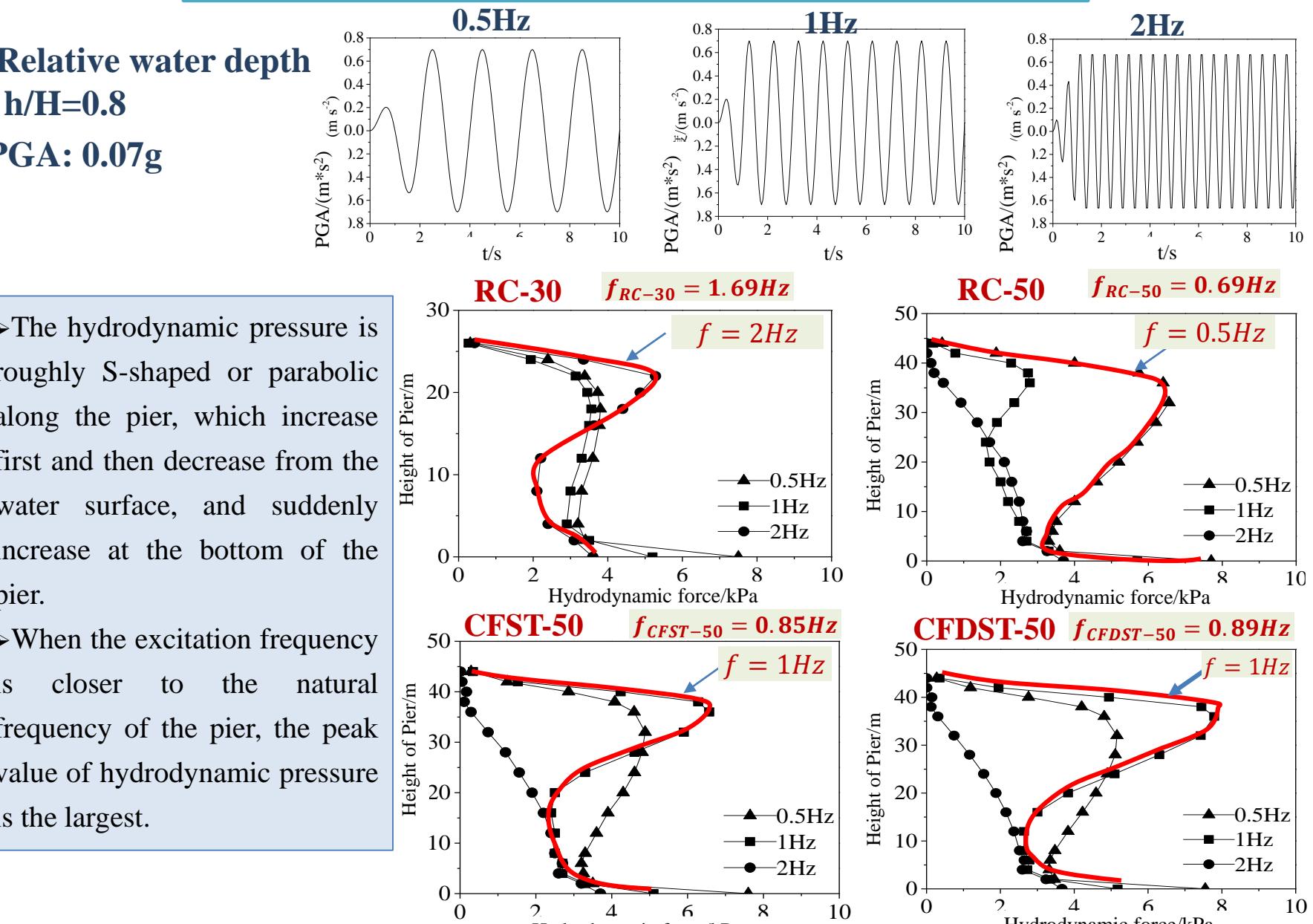


Seismic Analysis

Material Constitutive Models



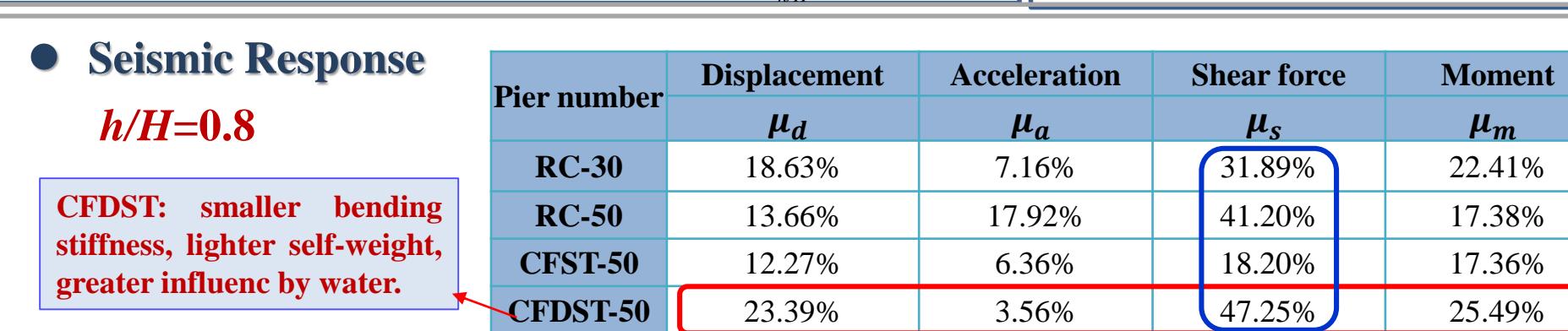
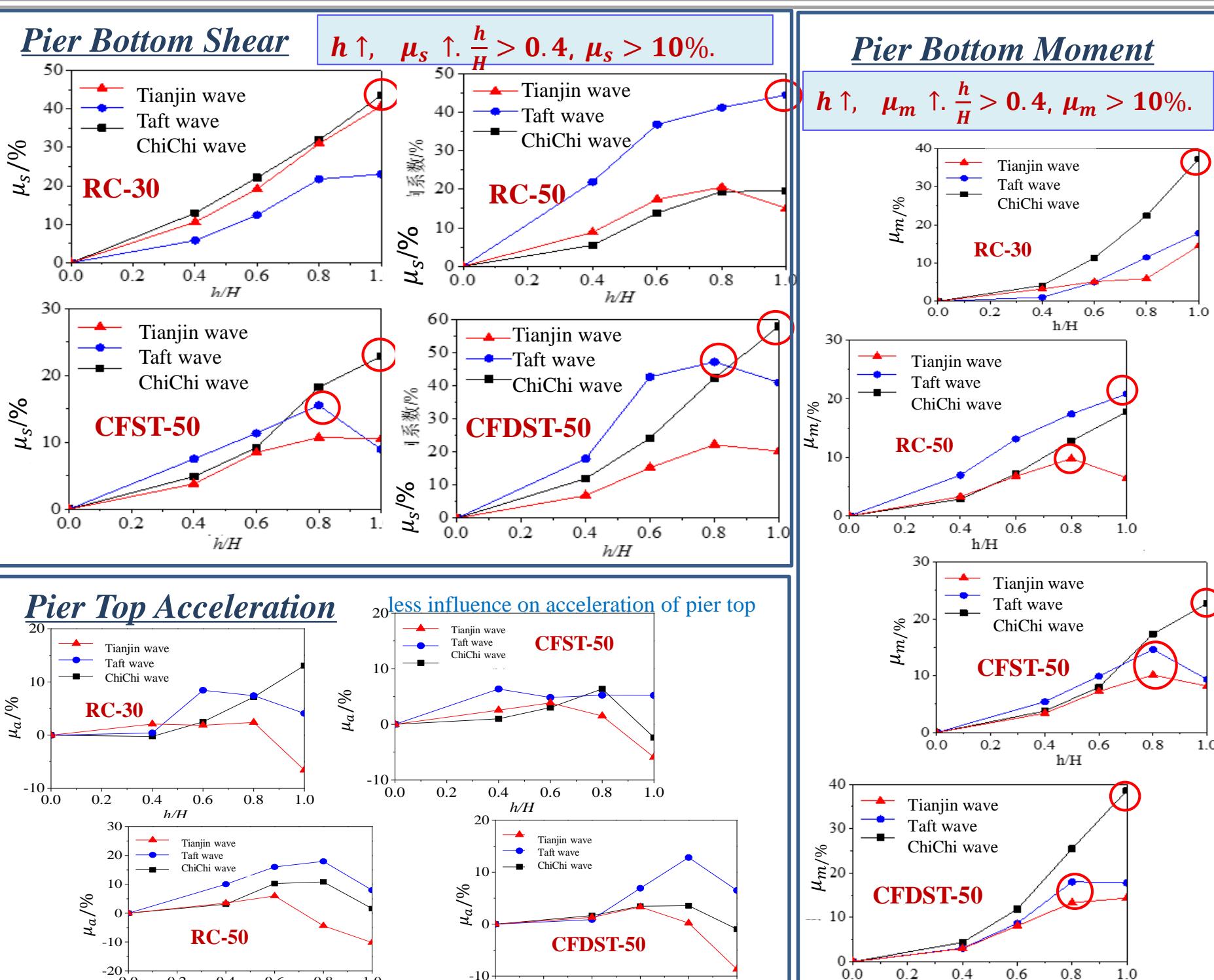
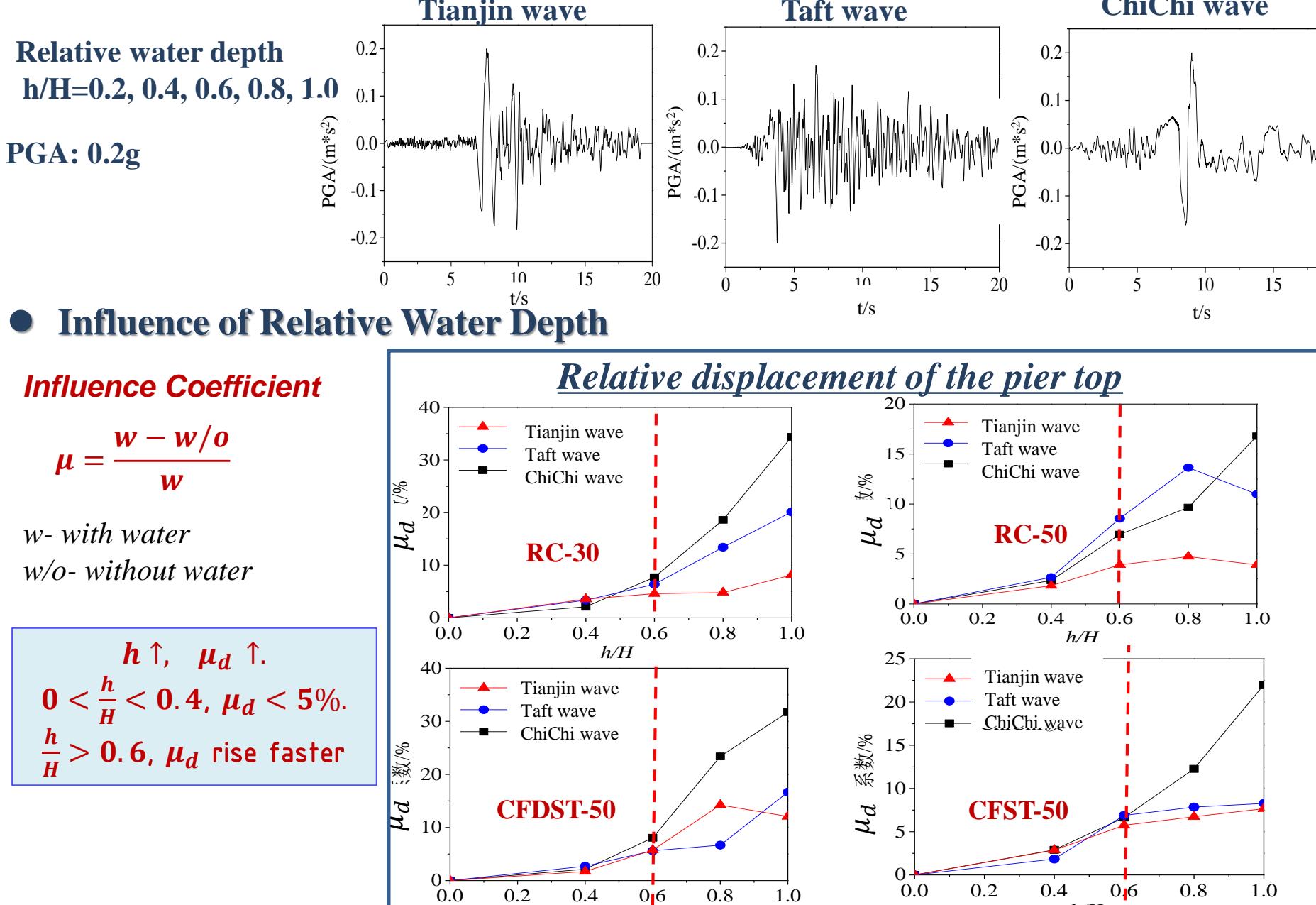
Time-history Analysis under Sine-wave Excitation



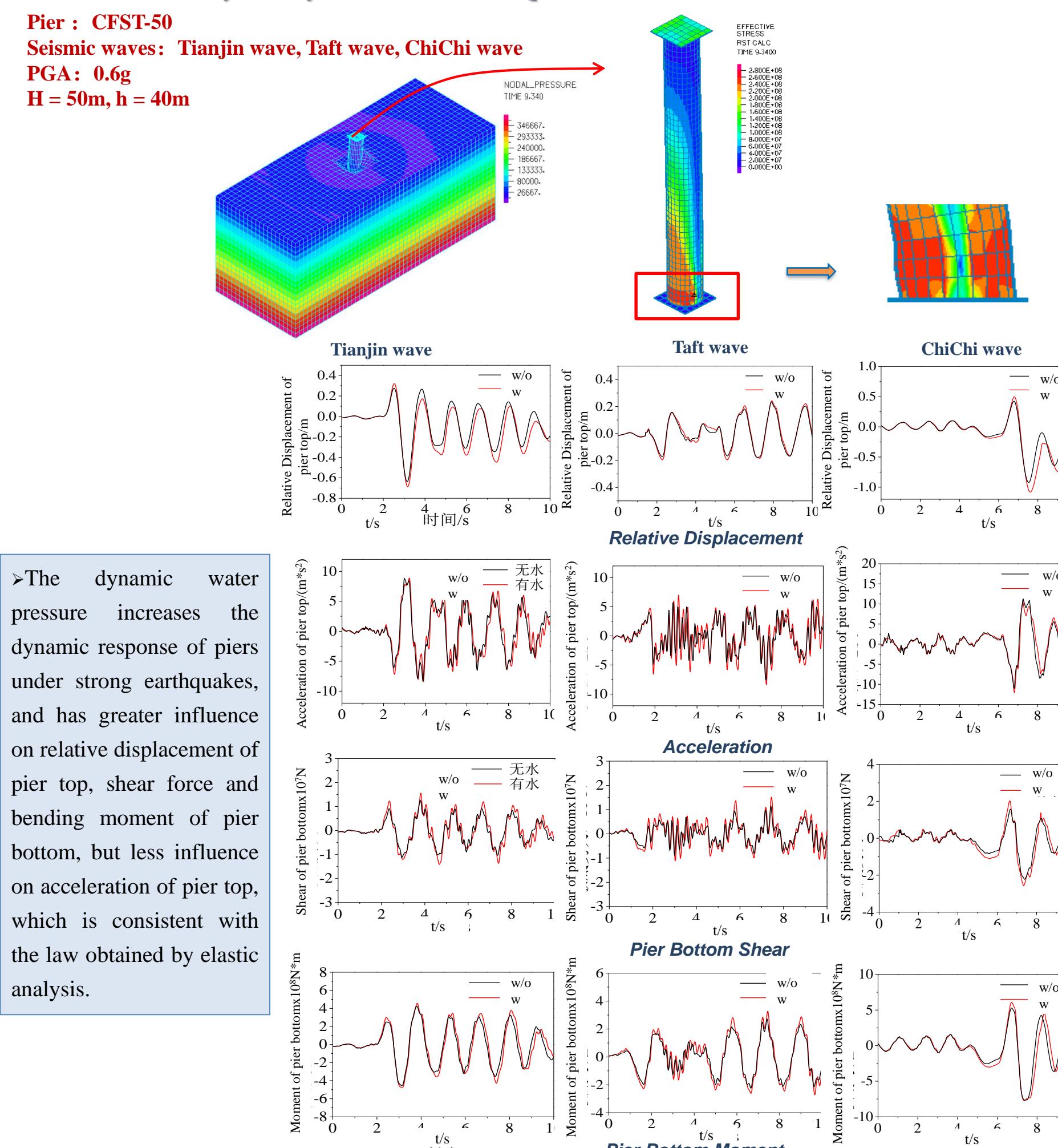
Conclusions

- When bridge pier is under water, the natural frequencies decrease, and the decreasing amplitude increases with water depth.
- Under seismic excitation, hydrodynamic pressure increases the maximum seismic responses, especially the relative displacement at pier top, and shear and bending moment at pier bottom. The lower the flexural stiffness and self-weight, the greater influence from hydrodynamic pressure.

Time-history Analysis under Earthquake Excitation

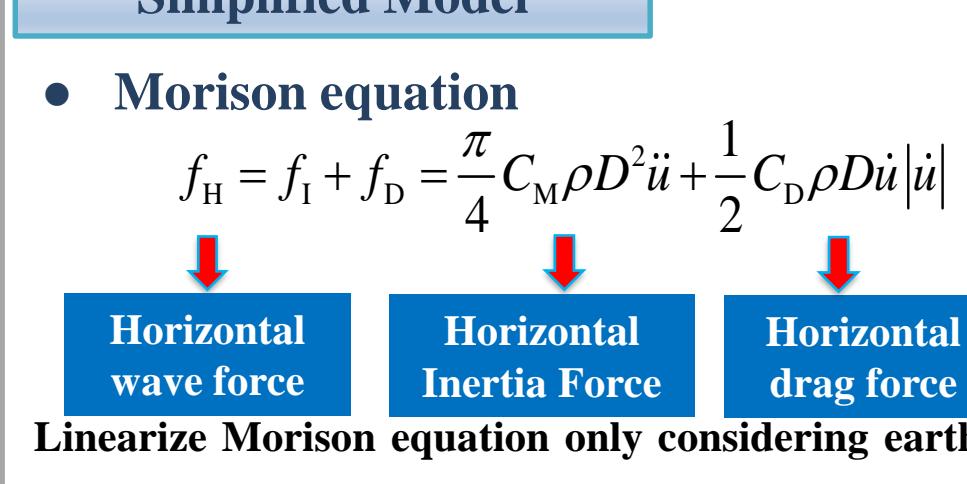


Time-history Analysis under Earthquake Excitation



- When pier slenderness ratio is higher than 53, the error using Morison Additional Mass Methods(MAM) is less than 10%. The water depth has little influence on the precision.
- Piers are more susceptible to seismic damaged under water. The PGA corresponding to the ultimate displacement of pier under water is 0.1g-0.2g lower than that on land. Under near-field earthquake excitation with impulse effect, the influence of the hydrodynamic pressure on the pier is more significant.
- Under seismic effects, CFDST piers have lower displacement at the pier top compared with CFST piers on land, but they are more affected by the hydrodynamic pressure under water. When the PGA is large, top displacement of both types of piers are very close.

Simplified Model



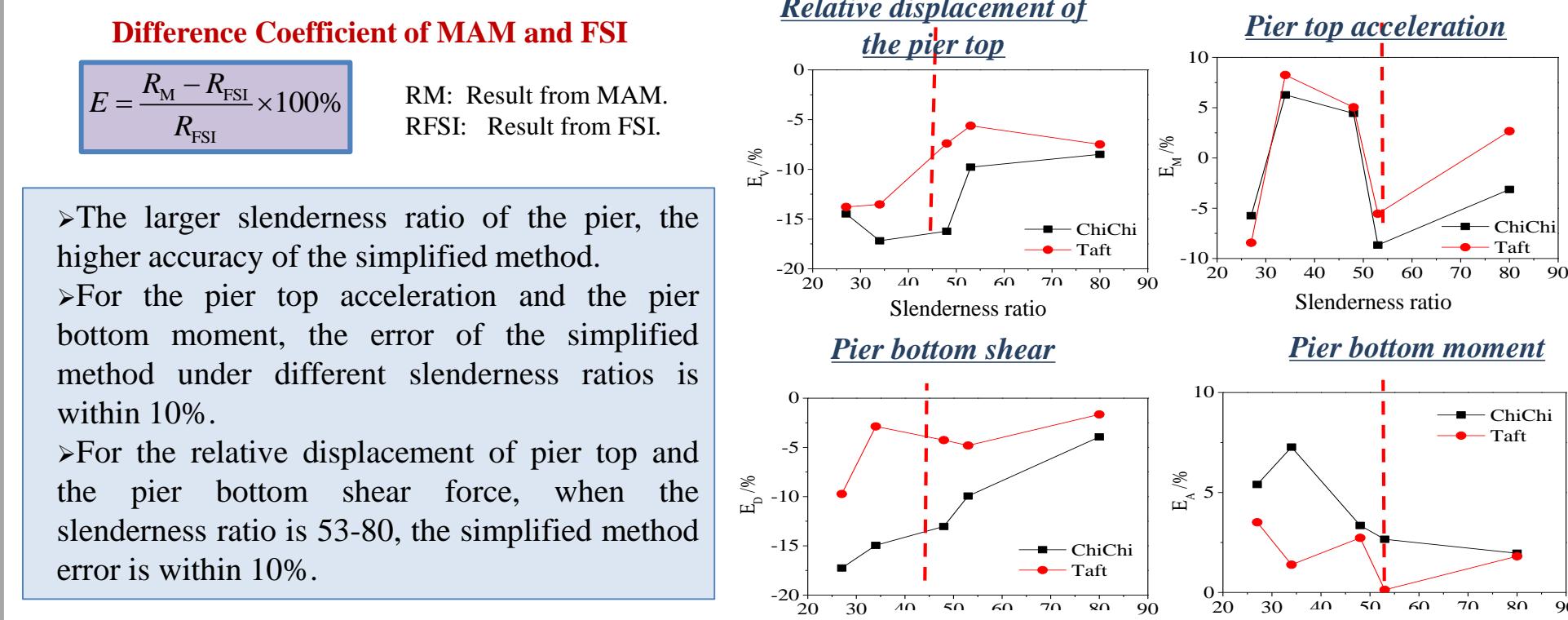
Linearize Morison equation only considering earthquake hydrodynamic pressure:

$$f_H = -M_w(\ddot{x} + \dot{x}_g) - C_w(\dot{x} + \dot{x}_g)$$

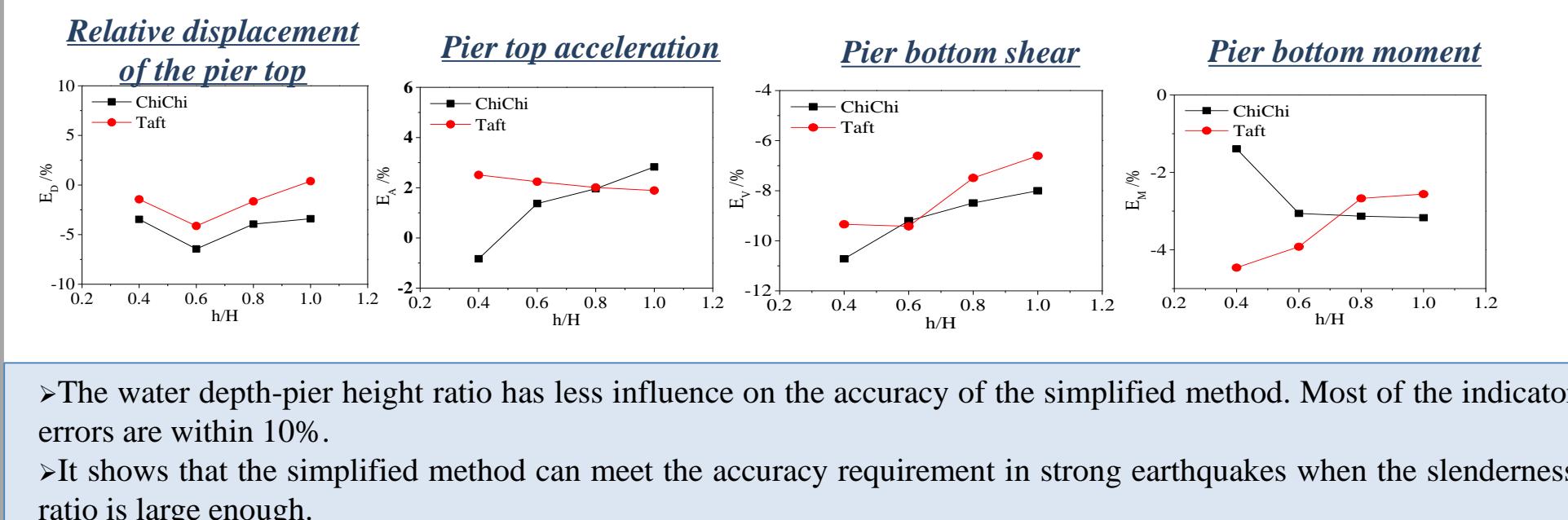
Hydrodynamic pressure can be considered as addition

$$M_w = (C_m - 1)\rho \frac{\pi D^2}{4} L$$

Effect of slenderness ratio on precision

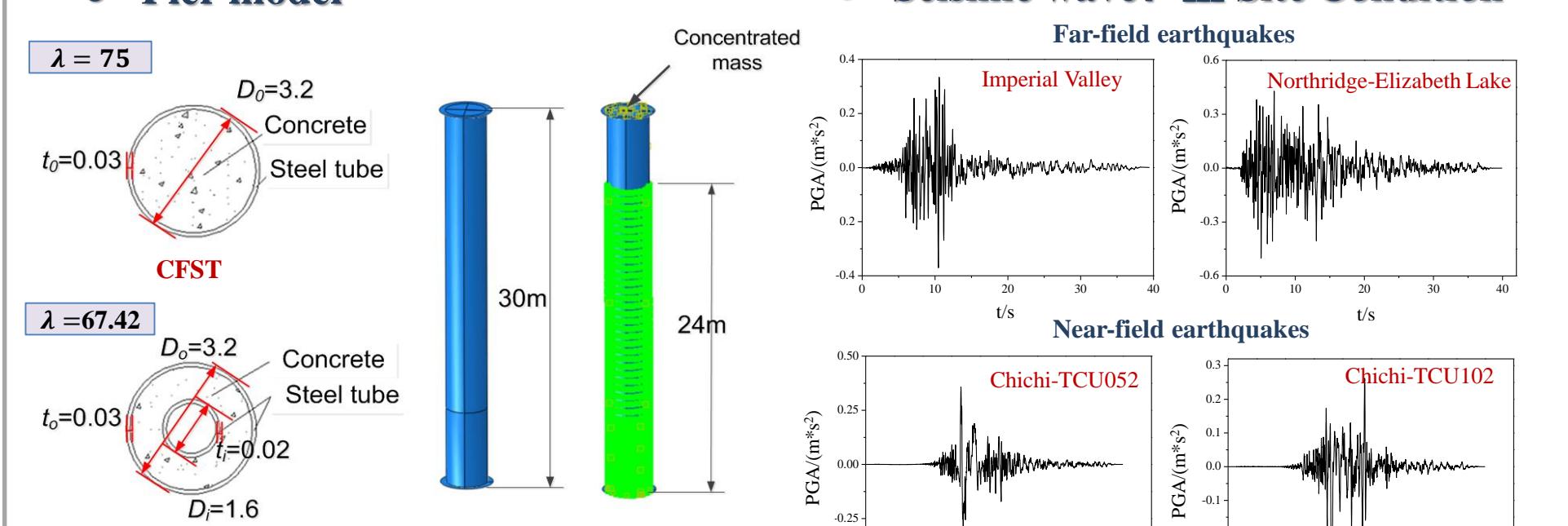


Effect of water depth-pier height ratio on precision

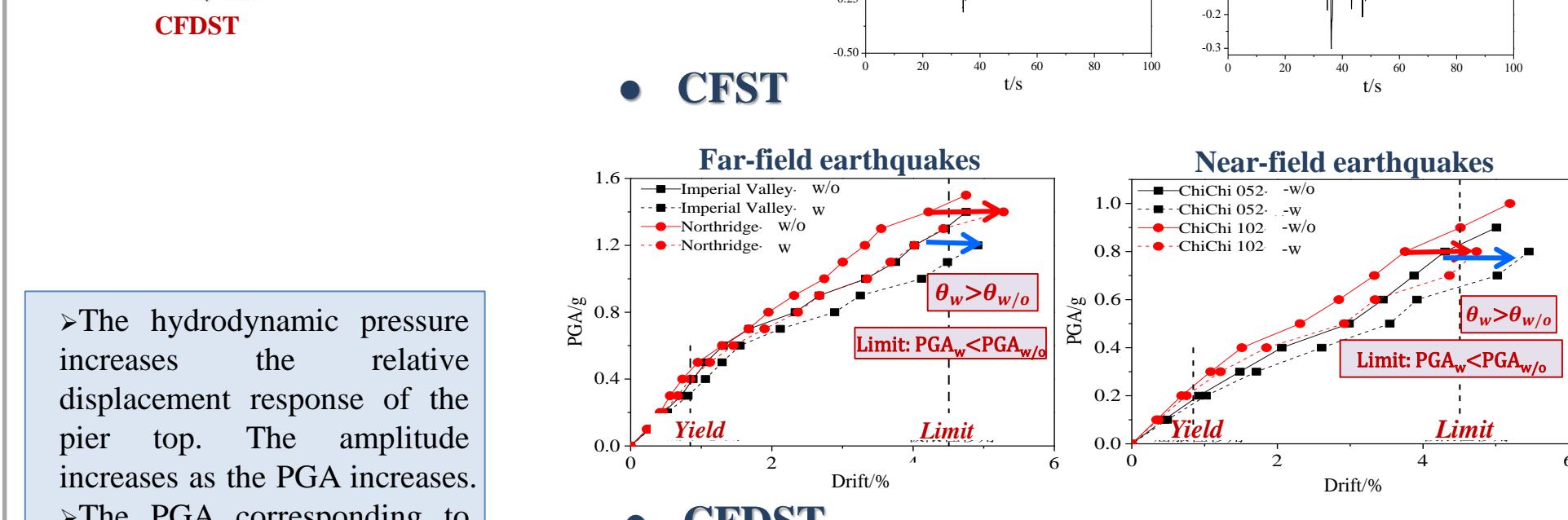


Incremental Dynamic Analysis (IDA)

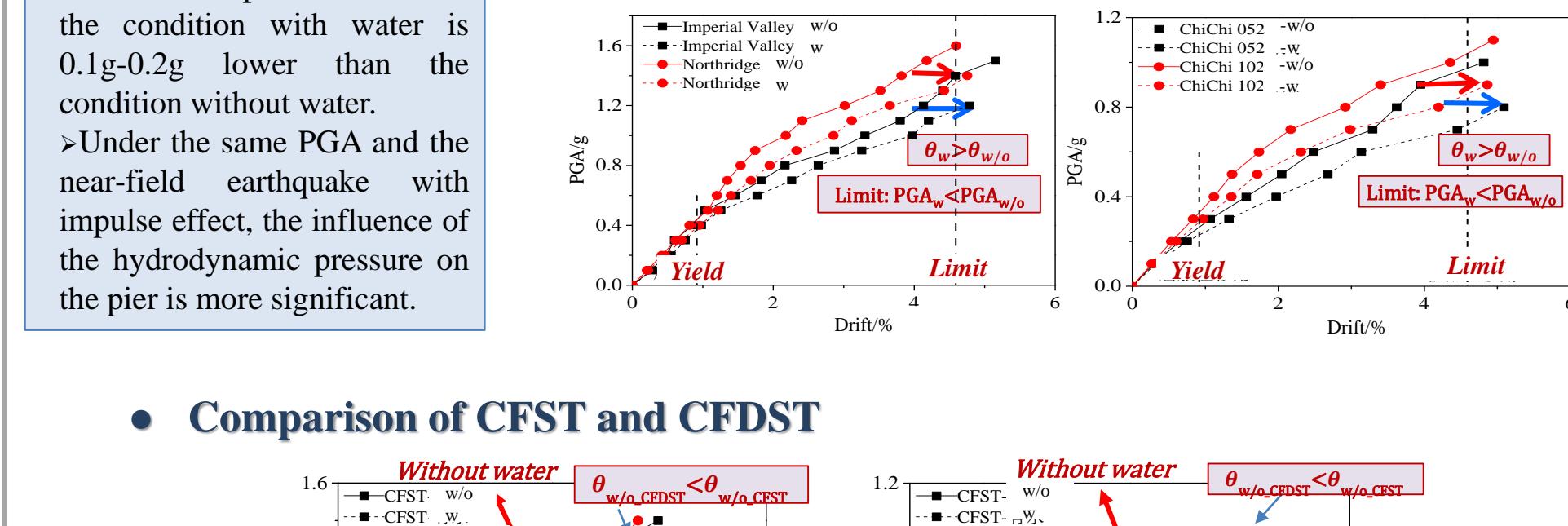
Pier model



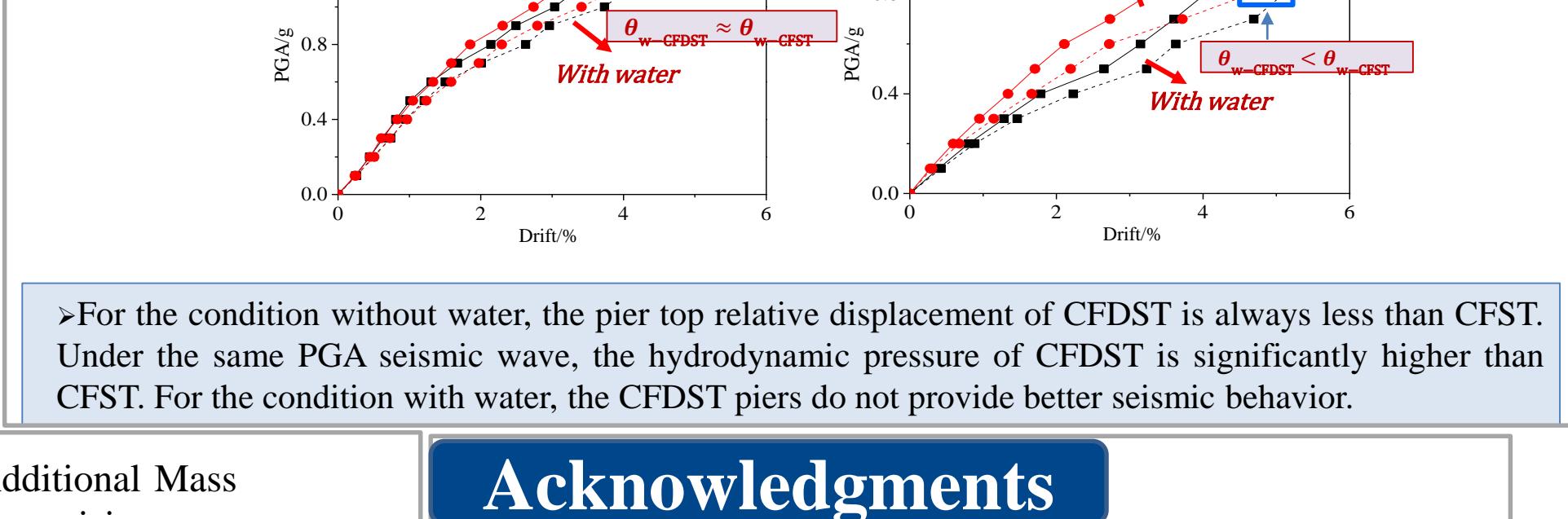
Seismic wave: III Site Condition



CFST



CFDST



Acknowledgments

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1. ZhaoQiuHong, Li Chenxi. Research status and prospects of seismic response of deep-water bridge piers. Journal of Traffic and Transportation Engineering, 2019.