Behaviour of monopile supported offshore wind turbine in liquefiable soil

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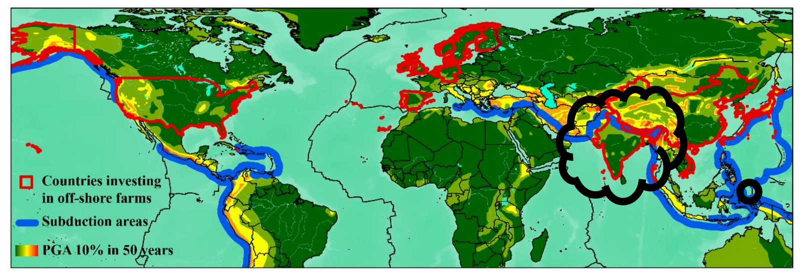
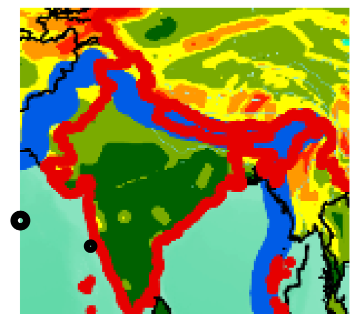
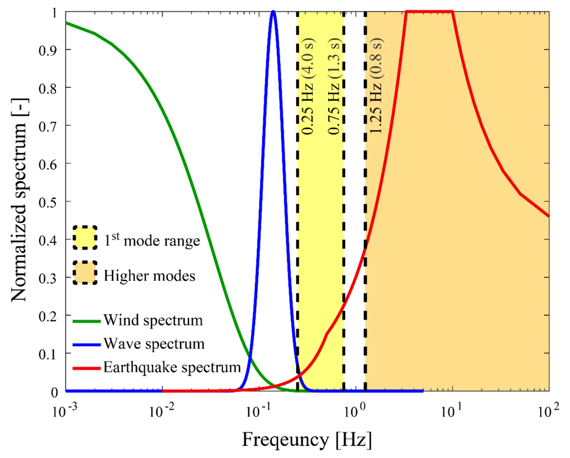
INTRODUCTION

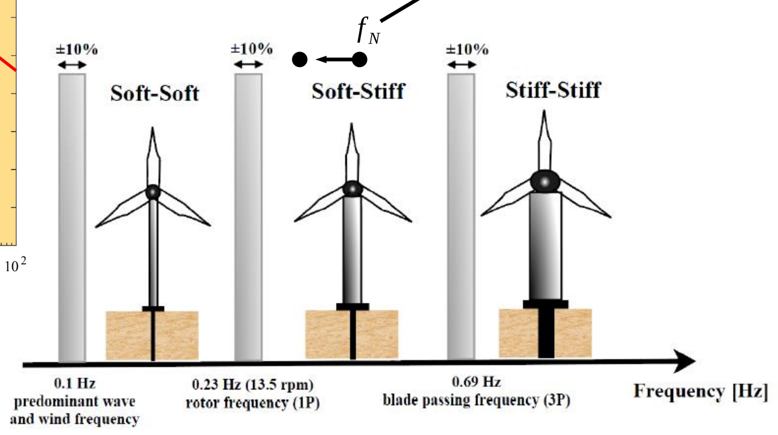
- **Conventional energy sources** - oil, gas and coal.
- Increases greenhouse gas emissions

Offshore wind turbine







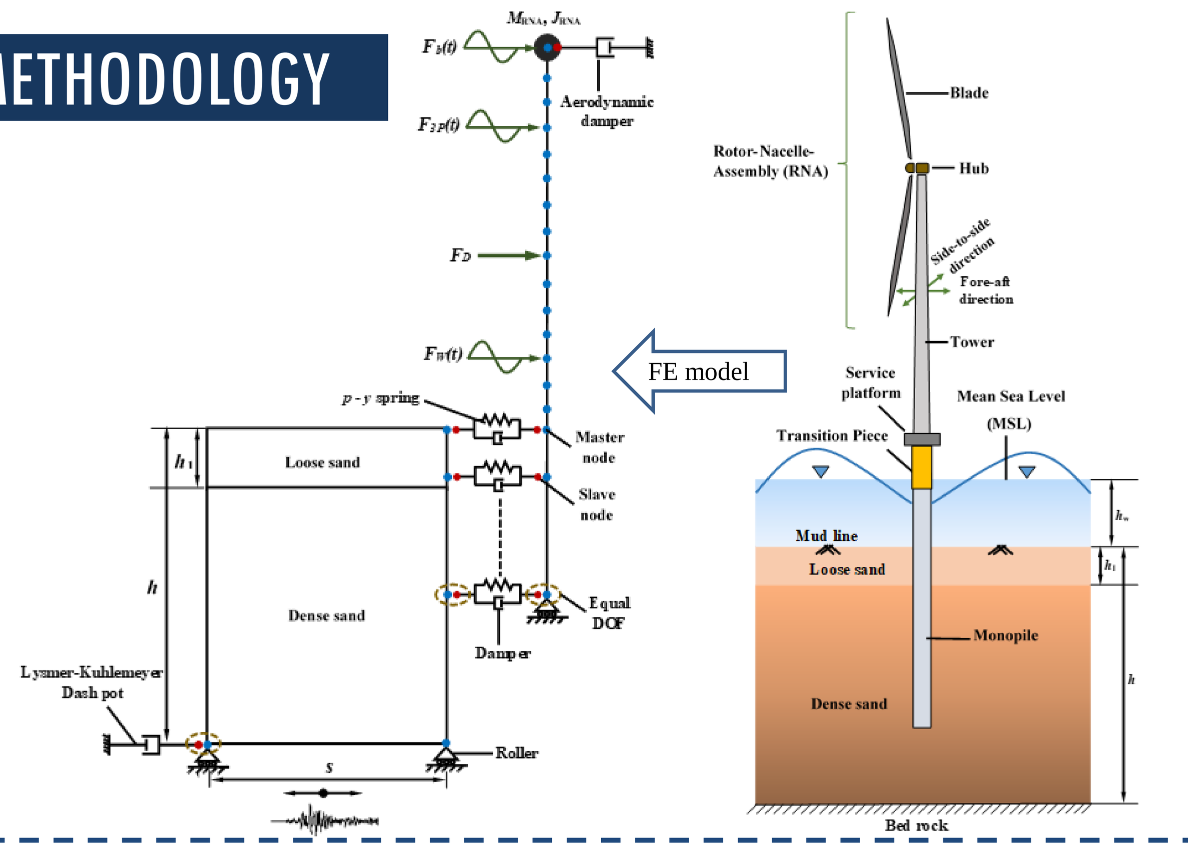


OBJECTIVE

➢ To examine the response of monopile supported OWT on layered sand deposit having different relative densities under combined action of environmental and seismic loading under various operational conditions.

Operational condition
- ✓ Operational
- ✓ Parked
- ✓ Operational and earthquake
- ✓ Parked and earthquake

METHODOLOGY



Modelling of monopile and tower:

✓ Linear beam column element with structural properties similar to National Renewable Energy Laboratory (NREL) 5 MW reference OWT.

Property	Value
Rotor diameter (m)	126
Hub height (above MSL) (m)	80
Rotor frequency (Hz)	0.12 - 0.22
Cut in wind speed (m/s)	3
Cut out wind speed (m/s)	25
Rated wind speed (m/s)	11.4
Tower Young's modulus (Pa)	210×10^9
Rotor mass (kg)	111×10^3
Tower mass (kg)	347460
Nacelle mass (kg)	240×10^3
Density of Tower (kg/m^3)	8500
Yield strength of steel (N/m^2)	355×10^6

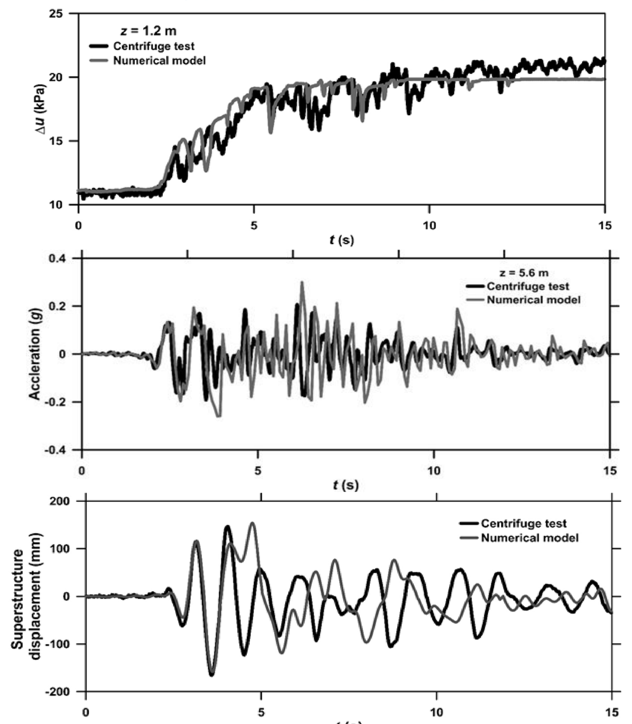
Modelling of pile soil interface:

- ✓ Nonlinear Winkler Foundation approach
- ✓ Spring constitutive behaviour: *PyLiq1* material

Modeling of damping

- ✓ Lysmer-Kuhlemeyer dashpot (1969)
- ✓ Constitutive behaviour: Viscous uniaxial material

Validation of model:



Modeling of soil:

- ✓ 9-node, quadrilateral elements with solid-fluid fully coupled material
- ✓ Soil constitutive model: *PressureDependMultiYield2* material. (based on the multi-yield-surface-plasticity theory)

Parameters	Soil 1	Soil 2
Relative density D_r (%)	55	80
Mass density (kg/m^3)	1950	2150
Low-strain shear modulus G_{max} (kPa) at 80 kPa mean effective confinement	25.04×10^3	37.08×10^3
Friction angle (degrees)	34.15	39.5
Phase transformation angle (degrees)	25.5	26
Peak shear strain γ_{max} at 100 kPa mean effective confinement	0.1	0.1
Contraction parameter c_1	0.045	0.013
Contraction parameter c_3	0.15	0.0
Dilatation parameter d_1	0.06	0.3
Dilatation parameter d_3	0.15	0.0
Liquefaction parameter l_1	1.0	0
Liquefaction parameter l_2	1.0	0
Initial void ratio e	0.70	0.55

Earthquake records

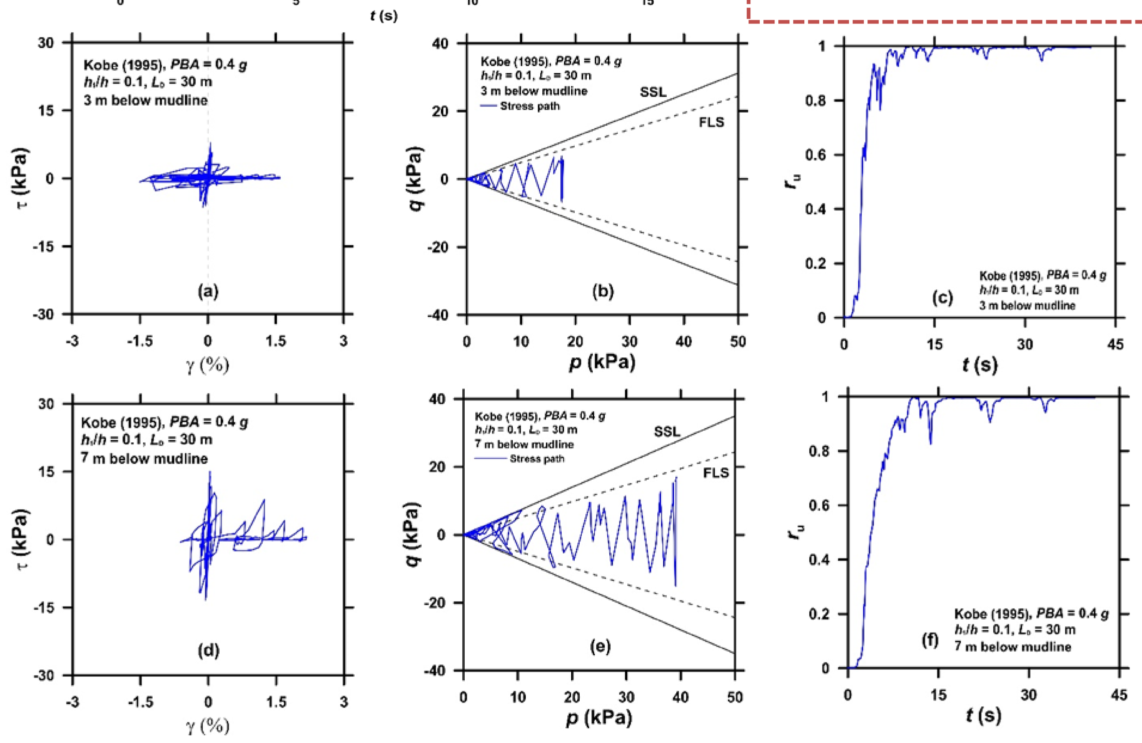
Record	Earthquake event	Record station	Magnitude	Epicentral distance (km)	Peak acceleration (g)	Duration (s)	SMA (g)	Arias Intensity (m/s)
1	ChalfantValley (1986)	Chalfant - Zack Ranch	5.6	20.4	0.16	40	0.037	0.104
2	Town of Big Bear Lake (2008)	Big Bear Lake - Fire Station	5.1	8.6	0.12	46	0.044	0.069
3	Parkfield (2004)	Parkfield - Fault Zone 14	6.0	12.9	1.29	21	0.474	7.355
4	Niigata (1964), Japan	701 RF DC	7.5	NA	0.23	87	0.076	0.544
5	Kobe (1995), Japan	Kakogawa (CUE 90)	7.2	NA	0.34	41	0.266	1.687
6	Artificial strong motion	NA	NA	NA	0.30	30	0.300	3.761

RESULTS AND DISCUSSIONS

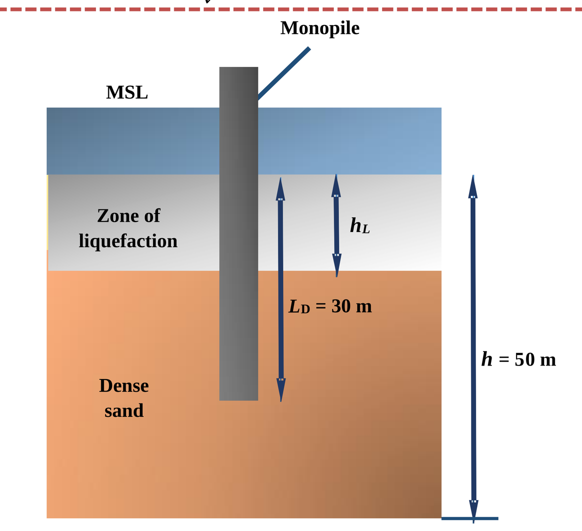
Assessment of depth of liquefaction

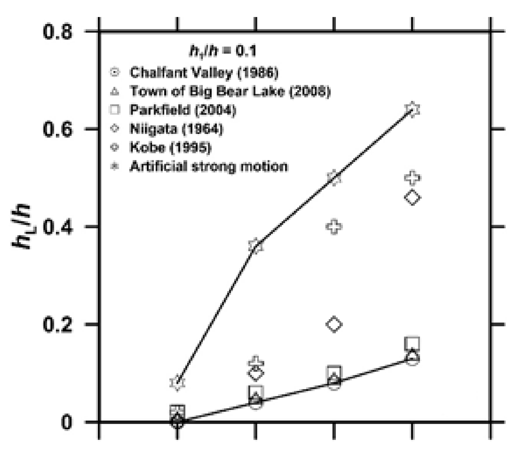
✓ Excess pore pressure ratio, $r_u \geq 0.8$ considered as zone of liquefaction

$$r_u = \frac{\Delta u}{\sigma'_v}$$



Seismic event	T (s)	T_m (s)	SMA (g)				I_A (m/s)			
			0.1g	0.2g	0.3g	0.4g	0.1g	0.2g	0.3g	0.4g
Chalfant Valley (1986)	40	0.28	0.024	0.048	0.072	0.096	0.043	0.17	0.40	0.72
Town of Big Bear Lake (2008)	46	0.34	0.035	0.070	0.105	0.140	0.045	0.18	0.38	0.68
Parkfield (2004)	21	0.43	0.037	0.074	0.111	0.148	0.044	0.18	0.40	0.71
Niigata (1964), Japan	87	1.54	0.033	0.066	0.099	0.132	0.103	0.41	0.93	1.65
Kobe (1995), Japan	41	0.54	0.077	0.154	0.231	0.308	0.140	0.57	1.28	2.27
Artificial strong motion	30	0.40	0.099	0.198	0.297	0.396	0.410	1.63	3.76	6.49

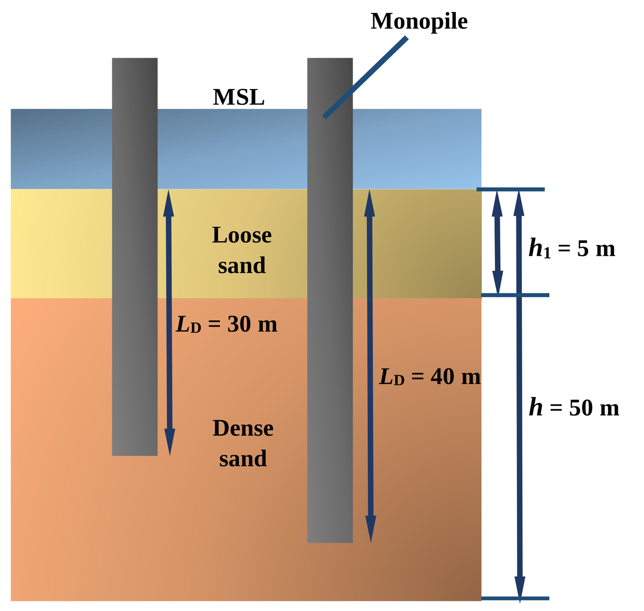


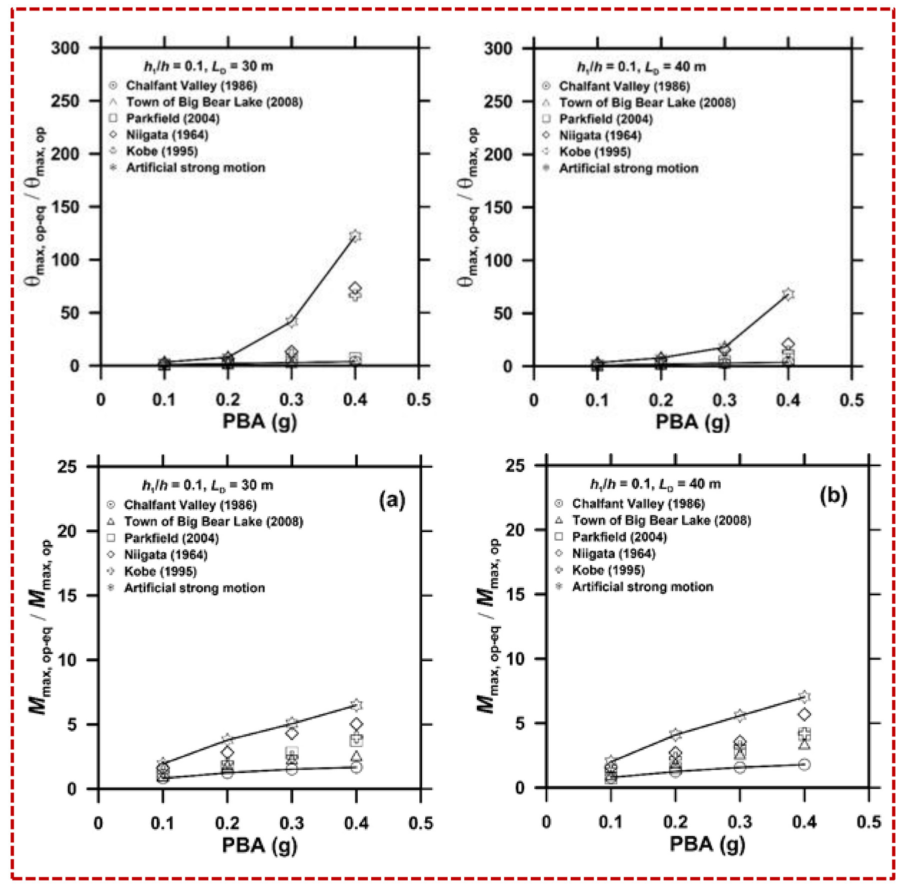


CONCLUSION

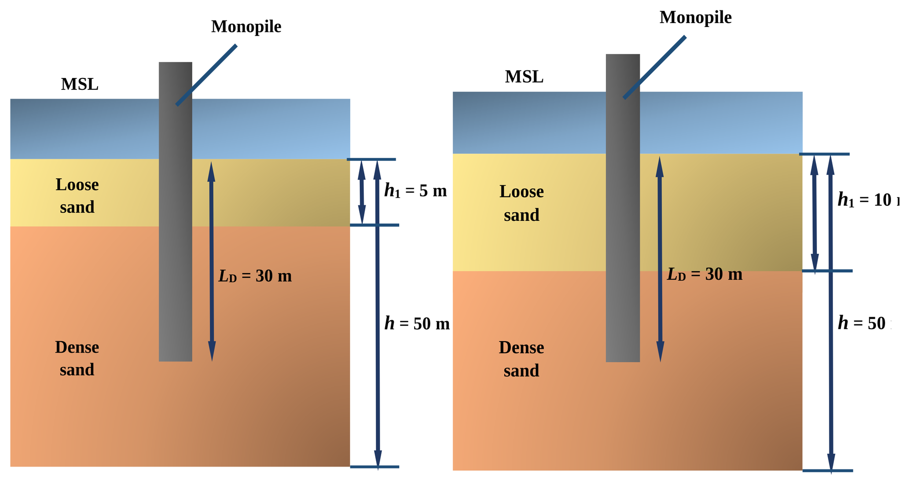
Response of OWT structure

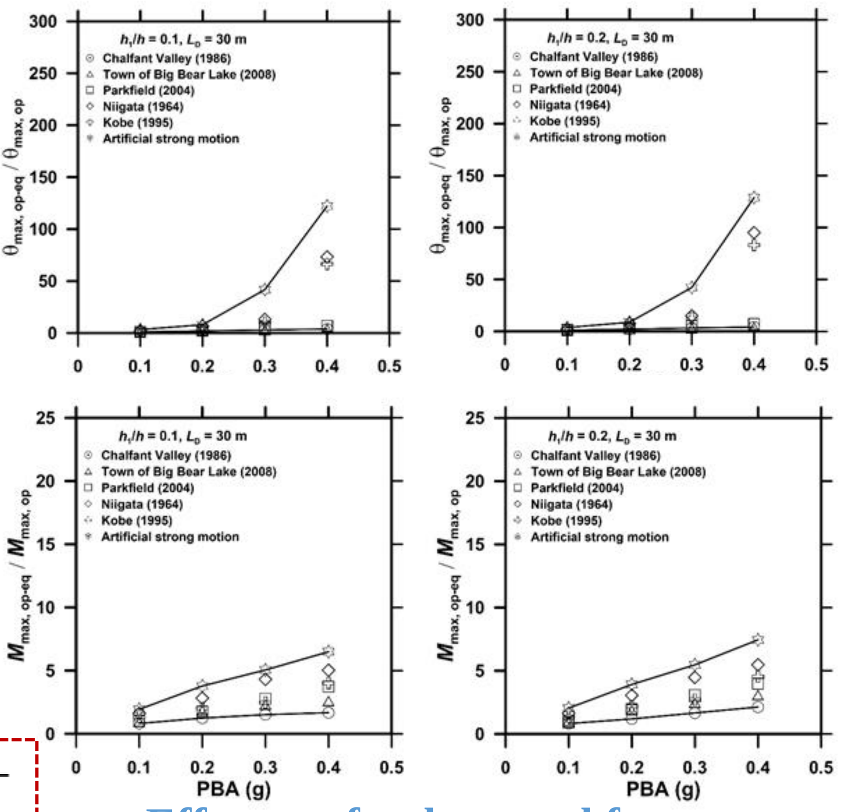
Effect of embedded depth of monopile



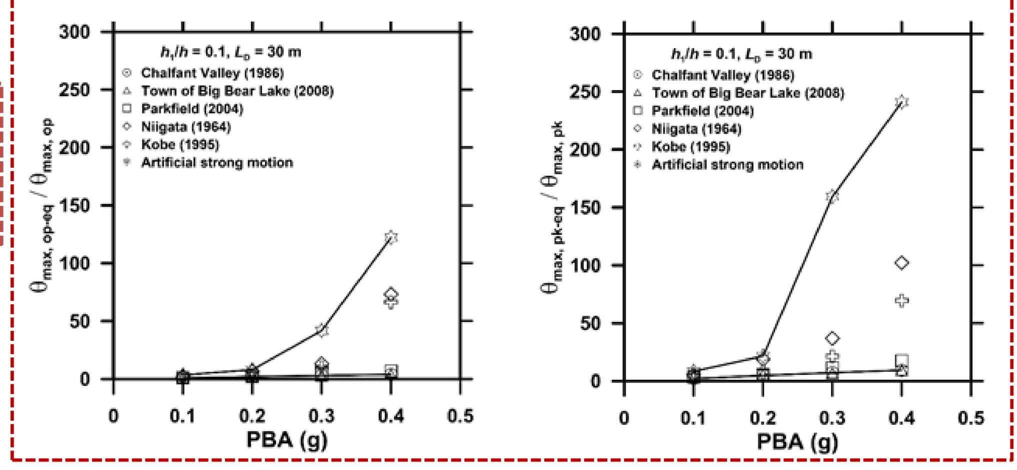


Effect of loose sand depth

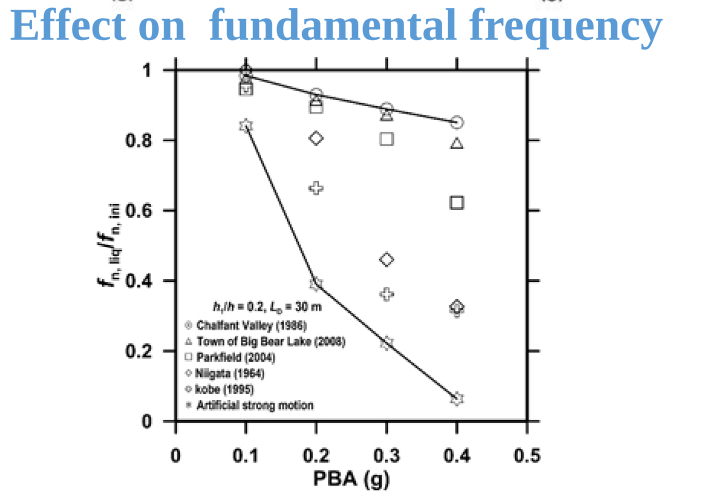




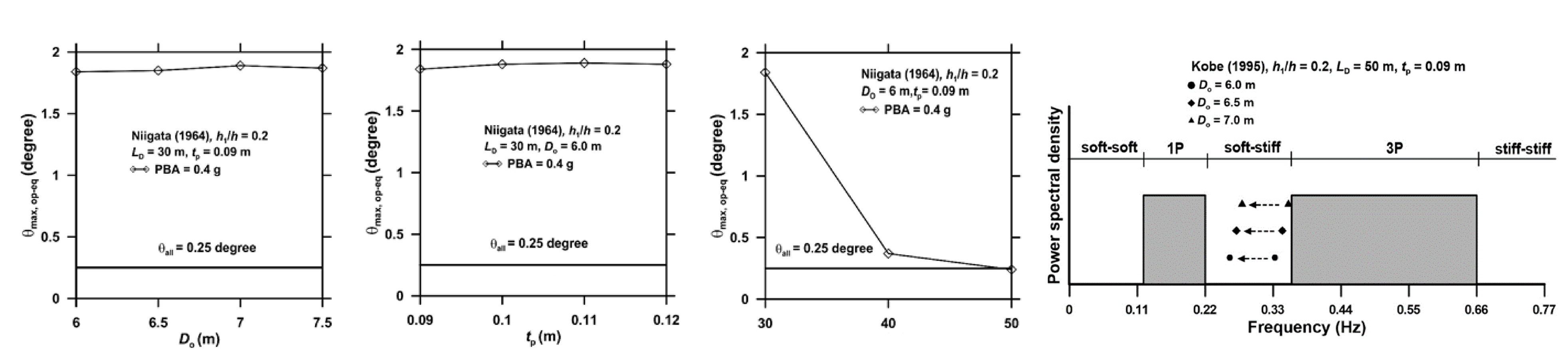
Effect of turbine operational state



Effect on fundamental frequency



Design guideline



- ➢ The depth of liquefaction is primarily dependent upon arias intensity and sustained maximum acceleration (SMA) of the seismic accelerogram. For a constant arias intensity, depth of liquefaction also increases due to an increase in SMA.
- ➢ The rotation of monopile and bending moment primarily depends on mean period of earthquake records rather than depth of liquefaction. Rotation and bending moment and of the OWT structure amplify if mean period of the seismic motion is close to the fundamental period of the OWT structure
- ➢ At both operational and parked condition of OWT, the wind and wave load dominates over seismic load during small seismic event (peak acceleration = 0.1g – 0.2g), whereas seismic load dominates over wind and wave loads at large seismic event (peak acceleration = 0.3g – 0.4g). Hence, a reasonable combination of wind, wave and seismic load shall be considered in case of seismic design of OWT.