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Dynamic response of offshore jacket platform including foundation degradation under cyclic loadings

Dongfeng Mao [a,b,*], Chao Zhong [c], Laibin Zhang [a,b], Gui Chu [a,b]

[a] China University of Petroleum-Beijing, Ocean Oil-Gas Research Center, Beijing 102249, China
[b] SAWS Key Laboratory For Oil–Gas Safety Engineering Center, Beijing 102249, China
[c] COTEC Offshore Engineering Solutions, Beijing, China

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ABSTRACT

A 1/10 scale model is investigated to study the influence of the foundation degradation on the dynamic response of an offshore jacket platform. Experiments were conducted in multi-layer saturated soil under different water depth. A vibration exciter which amplitude and frequency could be changed was employed to simulate realistic loads. The model was scaled using dimensional analysis according to the artificial mass similarity principle and Buckingham π theorem. The horizontal dynamic response under the foundation degradation after varying cyclic loadings acted were studied. FE models were designed by means of the lumped parameter method or the equivalent pile technique to handle the pile-soil interaction in ABAQUS to analysis dynamic behavior of the jacket platform. Experimental results shows that the foundation degradation is related to the motion amplitude and the frequency of the piles. The degradation will result in the jacket natural frequency depressed, but it has little impact on the system damping. Comparison of the numerical and experimental results shows that applying the lumped parameter model with *p-y* curve PSI element to simulate soil-pile-upper structure interaction can obtain much higher accuracy than using the equivalent pile technique. Fair agreement between the experimental and theoretical results was obtained.

1. Introduction

The offshore structures industry has been flourishing since 1940s. The continuous increase in water depth for which these structures have to be constructed necessitated the use of new modeling approaches to understand how these structures behave under realistic loads (Wisch, 1998; Adrezin et al., 1996). For an offshore jacket platform, not only huge the vertical weight loads from itself and upper models will act on, but also the horizontal cyclic loads from wind, wave, current, ice, earthquake and combination of them will continuously act on. The dynamic response of an offshore jacket platform supported on piles to marine environment loads has to be significantly influenced by the characteristics of the foundation (Asgarian and Lesani, 2009; Mostafa and El Naggar, 2004). Many researchers investigated the dynamic response of offshore jacket structures. Gudmestad and Moe (1996) recommended a unified approach for the selection of appropriate values for the coefficients used in the calculation of the hydrodynamic loads when they compared the API's and North Sea Design Practice methods and performed full-scale experiments to validate these values. With a numerical method, taking factors including wave height, wave period, choice of hydrodynamic coefficients C_M and C_o, and changes in deck mass and hysteretic structural damping into consideration, Sunder and Connor (1981) performed a sensitivity analysis on jacket platforms. In their calculation an equivalent simplified stick model was used. Some researchers calculated the natural frequencies and mode shapes of offshore structures in time domain with modal analysis (Karunakaran et al., 1997) or used exact Timoshenko pipe elements to determine the dynamic response of an offshore platform in the frequency domain (Horr and Safi, 2003). Ou et al. (2007) developed a damping isolation system to control the vibration of a steel jacket offshore platform. A 1/10 scale model of the structure was fitted with the damping isolation system and tested on a shaking table with it the ice and earthquake loads were simulated. They conducted numerical simulations and compared the numerical results with experimental results, and simulations and experimental results were in good agreement. Elshafey et al. (2009) designed a scale model theoretically and exp erimentally to investigate the dynamic response of an offshore jacket platform under random wave loads. The experiments were conducted both in air and in towing tank. Excellent agreement between the experimental and theoretical results was obtained.

The piles on which the jacket platform is supported move in cycles, so as to increase excess pore pressure of soil, weaken the

* Corresponding author at: College of Mechanical and Transportation Engineering, China University of Petroleum-Beijing, 18 Fuxue Rd., Changping, Beijing 102249, China.
E-mail address: maodf@cup.edu.cn (D. Mao).

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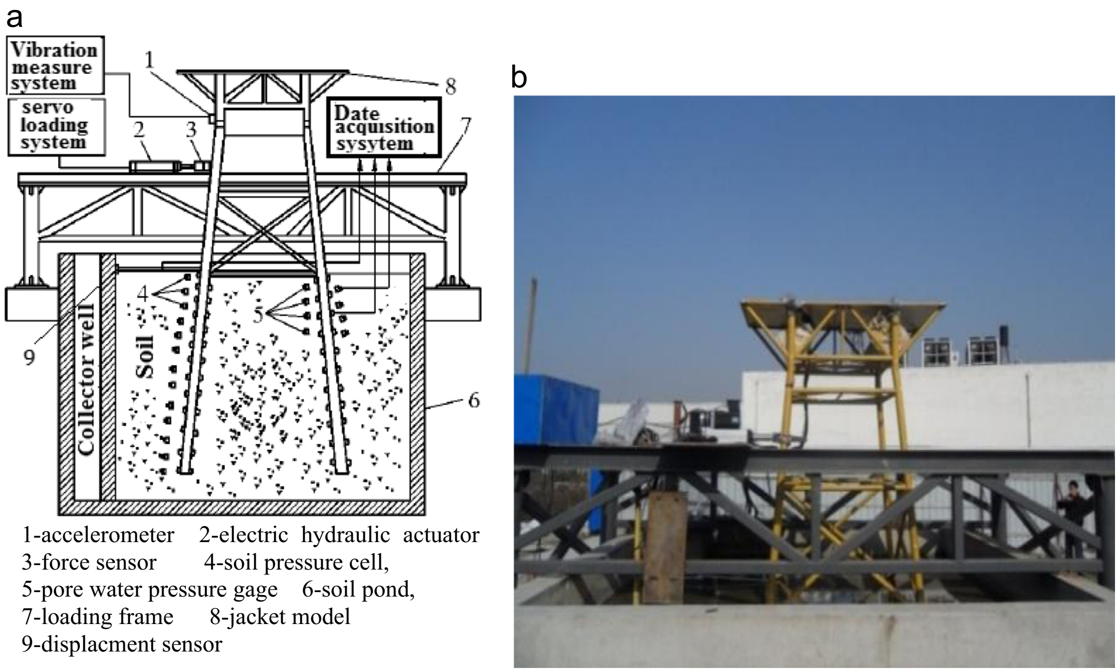

Fig. 1. Model experiment system. (a) Sketch map and (b) physical map.

Table 1
Dimensions and key physical parameters of model.

No.	Parameters	Dimensions	Similarity factor	1/10 scale mode
1	Physical dimension (L)	$[L]=[L]$	C_L	0.100
2	Mass density (ρ)	$[\rho]=[M][L]^{-3}$	$C_\rho=1.0$	1.000
3	Elastic modulus (E)	$[E]=[M][L]^{-1}[T]^{-2}$	$C_E=C_L$	0.100
4	Stress (σ)	$[\sigma]=[M][L]^{-1}[T]^{-2}$	$C_\sigma=C_L$	0.100
5	Vibration frequency (ω)	$[\omega]=[T^{-1}]$	$C_\omega=C_L^{-1/2}$	3.162
6	Exciting force (F)	$[F]=[M][L][T]^{-2}$	$C_F=C_L^3$	0.001
7	Exciting durance (t)	$[T]=[T]$	$C_t=C_L^{1/2}$	0.316
8	Exciting frequency (ω')	$[\omega']=[T]^{-1}$	$C_{\omega'}=C_L^{-1/2}$	3.162
9	Gravitational acceleration (g)	$[g]=[L][T]^{-2}$	$C_g=1.0$	1.000
10	Displacement (s)	$[s]=[L]$	$C_s=C_L$	0.100
11	Velocity (ν)	$[\nu]=[L][T]^{-1}$	$C_\nu=C_L^{1/2}$	0.316
12	Acceleration (a)	$[a]=[L][T]^{-2}$	$C_a=1.0$	1.000
13	Effective overburden pressure (σ')	$[\sigma']=[M][L]^{-1}[T]^{-2}$	$C_{\sigma'}=C_L$	0.100
14	Pore water pressure (u)	$[u]=[M][L]^{-1}[T]^{-2}$	$C_u=C_L$	0.100

Table 2
Parameters of sand.

Soil	Water content w (%)	Relative density D_r (%)	Effective unit weight γ (kN/m^3)	Liquid limit w_L (%)	Plastic limit w_P (%)	Cohesive force c (kPa)	Angle of friction φ (°)
Sand	21.1	45	19.6	33	21	0.1	20

Table 3
Parameters of clay.

Soil	Water content w (%)	Effective unit weight γ (kN/m^3)	Liquid limit w_L (%)	Plastic limit w_P (%)	Cohesive force c (kPa)	Angle of friction φ (deg)	ε_c
Clay	27.9	18.0	51	27	11.6	17.3	0.0217

Note: ε_c is the strain corresponding to half maximum stress in undisturbed soil undrained test.

Table 4
Test step.

No.	Step
1	Hammer pulse excitation
2	Sine cyclic loading, amplitude A, period T, and no. of cycles N
3	Hammer pulse excitation

Note: loading in displacement control way.

foundation and decrease the lateral soil resistance. There are a quite few publications which deal with the pile–soil interaction (PSI) and the foundation degradation. Matlock (1970) and Reese et al. (1974) investigated decay patterns of static resistance under cyclic loads for soft clay, hard clay and sand. The equations of static soil resistance suggested by them were adopted in API standard (API, 2000). And in further, Novak et al. (1978), Nogami and Novak (1980), Nogami and Konagai (1988), El Naggar and Novak (1996) and El Naggar and Bentley (2000) investigated the clay or sand dynamic resistances and analyzed the dynamic reactions of a pile under