

# Time Domain Simulation of Nonlinear Response of a Coupled TLP System

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## ABSTRACT

This paper presents a result of an analysis of the nonlinear interaction and response of the coupled ISSC-TLP System to the random seas in the time domain. The environmental load also includes the effect of the concurrent steady winds and currents. The first- and second-order wave-exciting forces are calculated using a robust higher-order boundary element method (HOBEM), while the nonlinear tendon dynamic analysis is performed using the three-dimensional hybrid element method with the updated Lagrangian formulation. The Morison equation is employed for the wave and current load on slender structures. The analysis is focused on the nonlinear responses due to the nonlinear environmental load and nonlinear interaction between the platform and tendons that includes the offset, setdown, large coupled surge-heave motion in the low frequency and resonant heave/pitch responses with the springing loads in the high frequency.

## INTRODUCTION

This paper presents an analysis of the nonlinear interactions and responses of the coupled ISSC-TLP in long-crested random seas in concurrence with the steady action of the wind and current.

The TLP system is a compliant platform whose mooring system has soft lateral and stiff vertical restoring forces, which create the lateral and vertical mode resonance motions in the low and high frequencies, respectively.

The responses of the TLP system near the resonance frequencies are activated by the second-order nonlinear wave-exciting forces. The nonlinear lateral environmental load induces a large drifting oscillation and brings the platform to its mean drifted position (offset) and the setdown of the platform. The TLP system then oscillates around the mean shifted position. Under the circumstances, the tendons may nonlinearly respond due to large geometrical displacement. The heave/pitch resonant motions induce springing tension loads in the tendons, which are important for the fatigue estimate.

The foregoing nonlinear characteristics have been observed by De Boom et al. (1984), Petrauskas et al. (1987), Kim et al. (1988) and others. Nwogu et al. (1990) investigated other exciting forces higher than the second-order. These works used an uncoupled model, i.e., the platform is assumed to be supported by the linear massless springs, hence the hull response is not affected by the dynamics of tendons. The uncoupled model therefore cannot deal with the effect of the nonlinear interaction between the platform and tendon motions. In particular, when the tendon stiffness varies nonlinearly in time, the nonlinear interaction can only be treated in the time domain.

In this paper, we developed a nonlinear first- and second-order wave force code using the higher-order boundary element method (HOBEM). The HOBEM code has been validated through com-

parison with the available benchmark data for a bottom-mounted vertical cylinder. In addition to this, we developed a nonlinear time domain three-dimensional tendon code that can deal with the nonlinear tendon deformation. The code is based on the three-dimensional hybrid finite element method and the updated Lagrangian formulation. The code was validated by comparing the computed results with the analytic solutions and those computed by ABAQUS. The time-domain integration of the incremental dynamic equation of the entire coupled TLP system was performed using the Houbolt integration scheme.

A numerical computation was carried out for the response of the ISSC-TLP system in a typical storm sea environment, using the aforementioned time-domain code TIOSTAMU. The head sea condition was assumed, which produces the surge, heave and pitch responses and tension forces in the tendons. Our analysis is focused on the offset, setdown, surge-heave coupling, resonance of the three mode motions and the springing load.

## ENVIRONMENTAL LOAD

The environmental fluid load on the coupled TLP system consists of the long-crested random wave force and the concurrent action of steady wind and current. The effects of unsteady wind and current are not considered in the present study. The wave impact and vortex shedding effects are also excluded. For the mean wind load and the mean current distribution, we employ the formulas recommended by API (1987).

The wave diffraction force is assumed to be unaffected by the current and is calculated using the HOBEM code. The viscosity effect is estimated by Morison's equation considering the relative particle velocity of the current and wave to the moving body. The viscous excitation is found to be negligibly small compared to the hydrodynamic wave-exciting forces.

All the environmental load is computed at the upright position of the TLP. The second-order wave-diffraction forces are computed in the bifrequency domain and converted into the time series by using the Volterra model. The resultant environmental load is then used as the external fluid loading in the incremental dynamic equation of the entire integrated TLP system.

In applying the HOBEM, special consideration is given to the singularities when the field point approaches the source point. These singularities are eliminated explicitly by using the polar

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KEY WORDS: Nonlinear interaction, higher-order boundary elementary method, tendon dynamics, time domain, springing load, coupled and uncoupled model.