I-632 Earthquake Response of Tension-Leg-Platforms in Steady Currents

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Introduction: Tension-Leg-Platforms (TLPs) are becoming increasingly popular for oil drilling at deep water sites. These structures consist of semi-submersible platforms having sufficient buoyancy to support the equipments and to develop the desired tension in the tethers. The tethers are anchored to the sea-bed foundation so that the platform acts like a moored semi-submersible vessel with very great flexibility in the horizontal direction but is quite rigid in the vertical direction. The tethers provide a horizontal restoring force in the offset condition. Also, they limit the vertical motion of the platform easing the problems of riser connections and the operation of production facilities. The behaviour of TLPs under dynamic excitations such as waves and earthquakes are being studied by many researchers. The high frequency motions of TLPs, which are likely to have an extremely important influence on the fatigue life of tethers, are affected by many factors such as higher order wave forces, earthquake forces and the nonlinear coupling with lateral tether dynamics. In this study the dynamic response of tethers subjected to current and earthquake forces is investigated. The objective is to clarify whether the offset conditions induced in the tethers by currents modify their earthquake response characteristics. The effect of vertical mode frequencies on the responses are also estimated. As the vibration mode and hence the responses are likely to be affected by the foundation characteristics the study is extended to include the dynamic soil-structure interaction.

Dynamic Analysis Method: The static deflected shape of the tether under steady current is firstly identified. The dynamic analysis for earthquake input is then carried out for the deflected configuration of the tether. The fluid loading due to the surrounding water is taken into account in the form of an added mass term and a hydrodynamic damping term. The tether is discretized by lumping masses at selected nodal points. The platform is represented by a mass at the top end of the tether. At each node three degrees of freedom corresponding to surge, heave and pitch motion are considered. The effect of pretension in the tether is included in the analysis in the form of a geometric stiffness term. The dynamic equations of motion for the tether-pile-soil system are derived using the substructure method. The natural frequencies and the vibration mode shapes of the total system are determined by eigenvalue analysis. The input ground acceleration is represented by Tajimi-Kanai's power spectrum for stationary conditions. The response analysis is carried out using the frequency-domain ranndom-vibration approach. The coupled axial and lateral responses are evaluated for both horizontal as well as vertical ground excitations.

Numerical Results and Discussions: For numerical simulations, the details of the Snorre TLP-tether system are used as the example so that the results can be correlated to actual conditions. This TLP is the world's largest so far with an installed displacement of 106520 tonnes. Table 1 shows the details of a typical tether of Snorre TLP used in this study. Figure 1 is the schematic diagram of the TLP-tether system. Figure 2 shows the examples of the deflected shape under steady current. They are proportional to the square of the current velocity. The pretenstion in the tethers prevent them from undergoing large deflection . The maximum horizontal deflection againt a current velocity of 2m/sec is 3.4m which is about 1.3% of its total length. Table 2 gives the natural frequencies of the tether-pile-soil system. Figures 3 to 6 are the examples of the displacement responses. For horizontal ground excitations, horizontal displacements of the tether increase with the input ground acceleration, but are nearly equal for all the cases of current velocities considered in this study indicating very little effect of current flow on the earthquake response characteristics in the horizontal direction. For horizontal ground excitations vertical displacements increase rapidly with the increase in current and earthquake forces. If the vertical displacements are excessive, this may cause slackening of tethers and may cause serious operational problems. For vertical ground excitations, both the horizontal and vertical displacements of the tether increase rapidly with the current velocity and ground acceleration. Studies on the high frequency vibration indicate that both horizontal and vertical displacements increase as higher modes are included in the response evaluation.

Table 1 Structural details of the tether

Outside diameter of tether (m)	0.81
Wall thickness (mm)	38
Cross-sectional area (m^2)	0.092
Length of tether (m)	262.5
Pretension (t)	1550
Weight of platform (t)	4737.5
Self-weight (t/m)	0.722
Modulus of elasticity (t/m^2)	$2.1 \cdot 10^7$
Modulus of rigidity (t/m^2)	$8.1 \cdot 10^6$
Water depth (m)	300

Table 2 Natural frequencies for the tether-pile-soil system (rad/s)

Vibration mode	$V_c = 0$	$V_c = 1m/s$	$V_c = 2m/s$
First	1.520	1.523	1.563
Second	3.107	3.108	3.109
Third	4.815	4.815	4.815
Fourth	6.694	6.695	6.696
Fifth	8.789	8.789	8.789

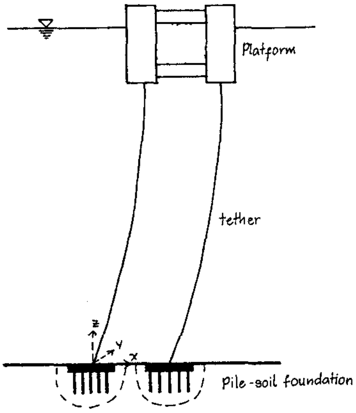

Fig.1 Schematic diagram of a TLP-tether system

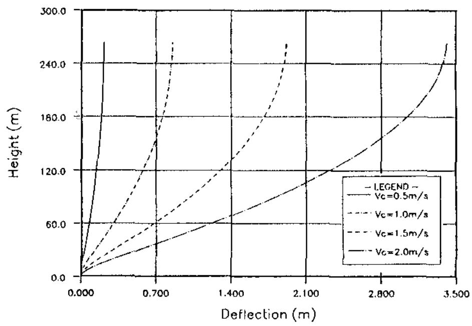

Fig.2 Static deflection of the tether

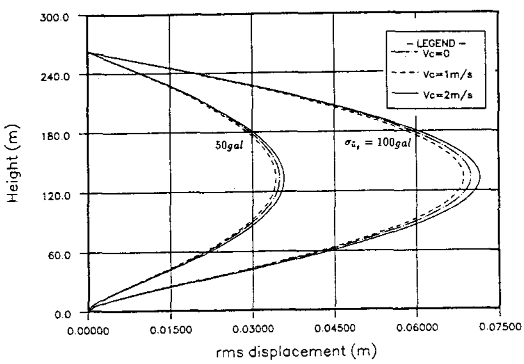

Fig.3 Horizontal displacements (for horizontal excitations)

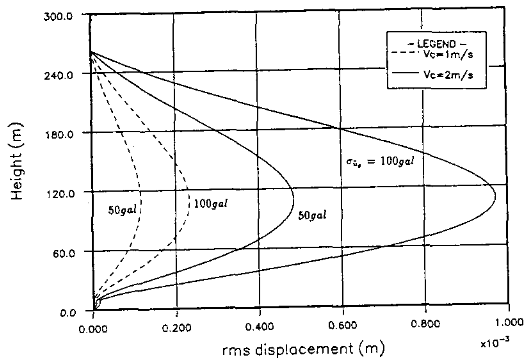

Fig.4 Vertical displacements (for horizontal excitations)

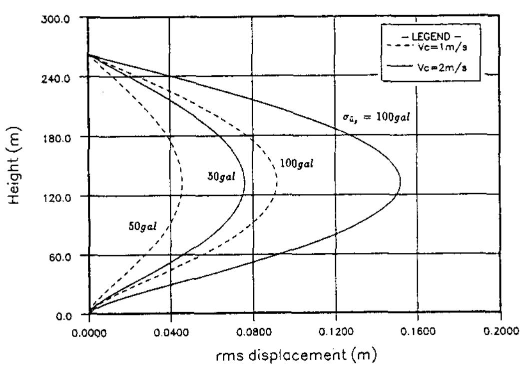

Fig.5 Horizontal displacements (for vertical excitations)

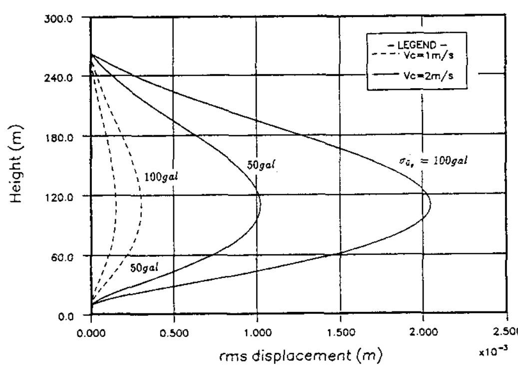

Fig.6 Vertical displacements (for vertical excitations)

Conclusions: Since the tethers are highly flexible in the horizontal direction and very rigid in the vertical direction due to pretension, their response behaviour in the vertical direction is of main interest to the designers. This research has shown that the earthquake response characteristics of the tethers in the vertical direction are significantly affected by the current flow and also by high frequency vibration modes.

Reference: Venkataramana, K."Earthquake Response of Tension-Leg-Platforms in Steady Currents", *Research Report*, Department of Engineering Science, Oxford University, 1991.