Earthquake Response of Tension Leg Platform under Offset Condition

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Introduction: A Tension Leg Platform (TLP) consists of buoyant platform moored to the sea bed through vertical tethers. The tethers are kept in tension by extra buoyancy of the platform. The main advantage of the TLP is that the heave motion of the platform is suppressed due to the axial stiffness of tethers. Thus the platform acts like a moored semi-submersible vessel with great flexibility in the horizontal direction but is quite rigid in the vertical direction.

A horizontal load such as wave or current will create an offset of the platform. When this platform under offset condition is subjected to a seismic excitation, the response characteristics of the platform and the tethers may deviate from their originally expected values based on a no-offset assumption. This paper examines the behaviour of tether under such a situation for horizontal and vertical seismic excitations.

Response analysis: The tether is modelled as a beam with fixed-end at the sea bed and roller-end at the top. The offset condition is caused by current flow. The static deflected shape of the tether under this current load is firstly identified. The dynamic analysis for earthquake input is then carried out for this 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 dynamic response analysis is carried out for a tether of the TLP model shown in Fig.1. The depth of water is 300m from mean sea level. Table 1 shows the structural details assumed for the analysis. The tether is discretized by FEM into 51 nodes and 50 elements. The platform is represented by a mass at the top end of the tether. At each node, there are three degrees of freedom, corresponding to surge, heave and pitch motion. The effect of pretension in the tethers is included in the analysis as a geometric stiffness term. The natural frequencies and the vibration mode shapes are determined by eigenvalue analysis. The input ground acceleration is represented using the power spectral density function of the modified Kanai-Tajimi type. The coupled axial and lateral responses are evaluated for both horizontal as well as vertical ground excitations.

Numerical Results and Discussions: Linearized Morison equation is used to compute the hydrodynamic force on the tether due to the surrounding water. The damping term is calculated by a cyclic procedure the essence of which is to alter the damping coefficients in an optimal manner. In this study reasonable convergence was attained in about four cycles of iteration. Fig.2 shows the deflected shapes under steady current. They are proportional to the square of the current velocity Vc. The pretension in the tethers prevent them from undergoing large deflection. Table 2 gives the natural frequencies for upto fifth vibration mode. The first natural frequency for all cases is lower than the dominant wave frequency range (0.314 to 1.570 rad/s or 4 to 20 secs) where as the frequencies corresponding to second and higher modes are higher than the dominant wave frequency range for the water depth of 300m, assumed for the TLP. Figures 3 to 6 are the examples of the displacement responses. For horizontal ground excitations, horizontal displacements of the tether increase with grounds acceleration but there are only slight variations in the values for the cases of current velocities considered in the study. However the vertical displacements increase rapidly with 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 horizontal and vertical displacements of the tether increase rapidly with ground acceleration.

Conclusions: Since the tethers of TLPs are higly flexible in the horizontal direction but are very rigid in the vertical direction due to pretension, their response behaviour in the vertical direction is of main interest to designers. When the tethers are perfectly vertical, they can be treated as aseismic structures whereas when offset condition is created, tethers undergo elongation under earthquake loading. The horizontal components of response displacements for horizontal excitations are mainly influenced by the intensity of earthquake loading alone and not much by the amount of initial offset. On the other hand, vertical components of response displacements for horizontal excitations, and both horizontal and vertical components of displacements for vertical excitations are strongly influenced both by the amount of current loading which causes the initial offset, and by the intensity of earthquake loading which causes the dynamic response.

Table 1 Structural details of the tether

Outside diamcter (m)	1
Wall thickness (mm)	40
Length of tether (m)	260
Modulus of elasticity (tf/m^2)	$2.1 \cdot 10^7$
Pretension (tf)	1500
Weight of platform (tf)	4737.5
Water depth (m)	300

Table 2 Natural frequencies for the tether (rad/s)

Vibration mode	Current velocity (m/s)		
	0.0	0.5	1.0
First	0.172	0.172	0.174
Second	1.944	1.948	2.006
Third	3.119	3.120	3.156
Fourth	4.702	4.704	4.730
Fifth	6.604	6.607	6.623

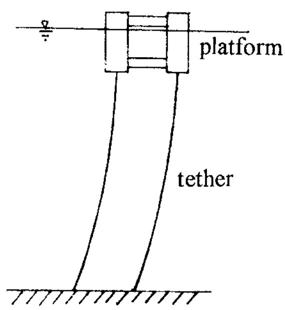

Fig.1 Schematic diagram of a TLP-tether system

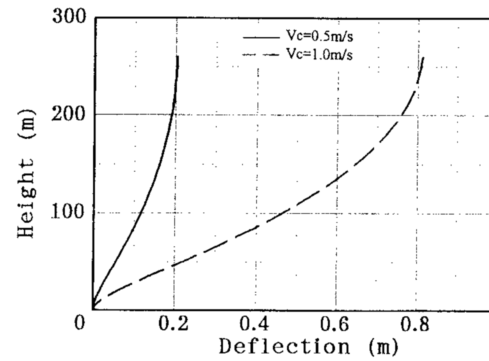

Fig.2 Static deflection of the tether

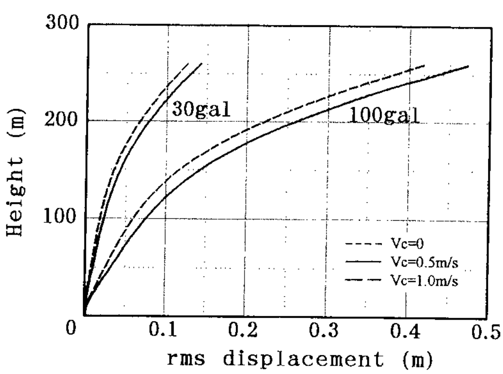

Fig.3 Horizontal displacements (for horizontal excitations)

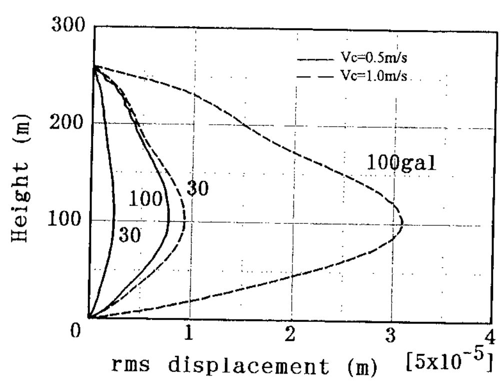

Fig.4 Vertical displacements (for horizontal excitations)

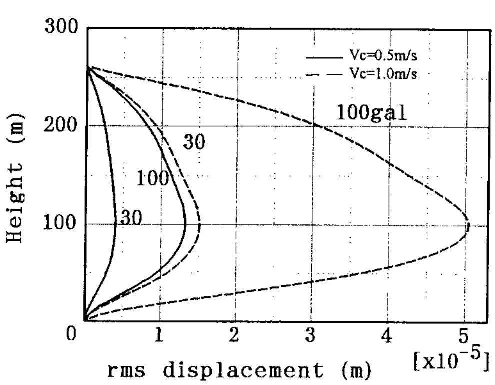

Fig.5 Horizontal displacements (for vertical excitations)

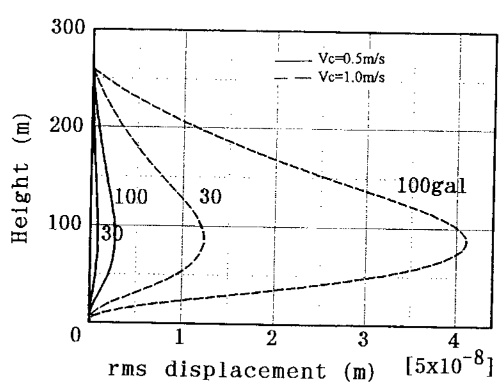

Fig.6 Vertical displacements (for vertical excitations)