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Title of thesis – **Seismic Response of Multi-Hinged Articulated Offshore Tower**

Abstract

Articulated towers are among the compliant offshore structures that are light weight and slender in configuration. These are economically attractive for deep water applications because of their reduced structural weight. They are used for operations such as pre-drilling, production, flaring of waste gases, tanker mooring, field controlling and loading / off-loading terminals. Most researchers have examined the tower as an upright rigid pendulum attached to the sea floor via a pivot having 1 or 2 degrees of freedom under hydrodynamic loading only. Only few have dealt with the earthquake response analysis of articulated offshore towers.

Herein a simplified model of multi-articulated offshore tower is analyzed to calculate the overall nonlinear global response due to earthquake and hydrodynamic loads in time-domain by employing 24 sets of real earthquakes (near-fault as well as far-fault). The effects of nonlinearities due to drag force, variable buoyancy, submergence and added mass along with the geometry are taken into account. A computer code (EAMAT'09: Earthquake Analysis of Multi-Articulated Offshore Tower) has been developed for responses due to seismic sea loadings as well as due to high random sea waves using Microsoft Fortran PowerStation.

The offshore tower is modeled as an "inverted pendulum" with two cylindrical shafts (lower and upper) connected by articulated joints leading to a 2 DOF model. One being at the sea bed is subjected to horizontal and vertical seismic excitations. The shafts are idealized as a stick model, divided into finite number of small size rigid elements, each of uniform property with appropriate masses, areas and volumes lumped at the nodes. Structural damping matrix has been assumed to be mass and stiffness proportional, based on the initial values of mass and stiffness

matrices. The nonlinear dynamic equation of motion is formulated using Hamilton's variational principal. The resulting equation of motion in terms of rotational degrees of freedom for the structural system can be expressed as:

$$\left[M^*\right]\begin{Bmatrix}\ddot{\theta}_1\\ \ddot{\theta}_2\end{Bmatrix} + \left[C_{hyd}\right]\begin{Bmatrix}\dot{\theta}_1\\ \dot{\theta}_2\end{Bmatrix} + \left[K\right]\begin{Bmatrix}\theta_1\\ \theta_2\end{Bmatrix} = \begin{Bmatrix}M_{\theta 1}\\ M_{\theta 2}\end{Bmatrix}$$

Where $M_{\theta 1}, M_{\theta 2}$ are the generalized moments due to non-conservative forces (earthquake and wave loads), calculated using modified Morison equation, for the lower and upper shaft's respectively. The obtained equations of motion are solved in time-domain with Newmark-β method incorporating nonlinearities in an iterative fashion.

A 580 m high multi-articulated offshore tower in a water depth of 530 m is considered for numerical analysis. The rotational degrees of freedom are confined in XZ-plane, i. e. the plane of environmental (earthquake, wave and current) loading. Responses in the form of time histories of responses under different seismic and random sea environments are examined. Statistical characteristics of responses (stresses) obtained due to different near-fault and far-fault records of earthquake excitation are used as the basic input for the performance (reliability indices and probability of failure) of the critical joint under ultimate limit state conditions arising due to seismic sea criteria.

In general, the response characteristics of multi-articulated offshore tower subjected to near-fault ground motions are considerably greater than those from far-fault earthquake records especially with pulse-type waves. Study showed that the structural response parameters will change from nearly elastic case to highly inelastic levels. With the inclusion of the vertical ground motions, the demand in the axial thrust at the base articulation has increased which in turn seems to have an effect on moment and shear demands at their respective critical sections.

The inclusion of seismic forces with wave forces has caused a major difference in the response statistics. High probabilities of failure are obtained due to seismic sea loadings, and therefore, are important to be considered to assess the performance under ultimate limit state. In most of the seismic sea loading cases, the reliability indices due to far-fault responses are on the higher side as compared to the near-fault response. Owing to low probability of failure due to far-fault seismic sea loading, target reliability can be easily achieved.