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Experimental research on fatigue property of steel rubber vibration isolator for offshore jacket platform in cold environment

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ABSTRACT

Jacket platform is the most widely used offshore platform. Steel rubber vibration isolator and damping isolation system are often used to reduce or isolate the ice-induced and seismic-induced vibrations. The previous experimental and theoretical studies concern mostly with dynamic properties, vibration isolation schemes and vibration-reduction effectiveness analysis. In this paper, the experiments on steel rubber vibration isolator were carried out to investigate the compressive properties and fatigue properties in different low temperature conditions. The results may provide some guidelines for design of steel rubber vibration isolator for offshore platform in a cold environment, and for maintenance and replacement of steel rubber vibration isolator, and also for fatigue life assessment of the steel rubber vibration isolator.

1. Introduction

Among the various types of offshore structures, the steel jacket platform is the most common in use, with multi-functions for oil exploration, drilling as well as for production. Conventionally, such platforms operate up to a depth of about 100–150 m. They are usually built from tubular steel members. These structures have a very short vibration period ranging from 2 to 8 s. Apart from the operational loads, they also subject to environmental loads such as wind, wave, ice and earthquake loads.

The safety of structures can usually be ensured by increasing their stiffness so as to shift the natural frequencies away from the resonating frequencies. However, this approach is generally costly, involving excessive construction materials. An alternate approach is to implement a passive and/or active control mechanism to regulate the structural motion as desired (Garcia and Soong, 2002). Passive control devices do not require external energy but with some inherent limitations. On the other hand, an active control mechanism can be effective over a wide frequency range with the desired reduction in the dynamic response. The active control approach is the current concern of many researchers and there are several attempts exploring its applications to offshore structures. Responses of offshore platforms with an actively tuned mass damper installed have been studied by Kawano (1993) and Kawano and Venkataramana (1992) and it is shown that such mechanism is quite effective in reducing the response of platforms due to wave loading. Lee (1997) demonstrated the effectiveness of mechanical dampers using stochastic analysis for offshore platform. Abdel-Rohman (1996) studied the applications of certain active and passive control mechanisms to reduce the dynamic response of steel jacket platforms due to wave loading. Suneja and Datta (1998, 1999) demonstrated the effectiveness of an active control system for articulated leg platforms in view of minimizing the wave-induced response. The effectiveness of the lateral vibration control was examined by Wang (2002) for wave-excited response of offshore platforms with magneto-rheological dampers. Mahadik and Jangid (2003) studied the response of offshore jacket platforms with an active tuned mass damper under wave loading. Although, there had been several studies on effectiveness of the active and passive control mechanisms in controlling the response of offshore platforms under wave loading, few studies had reported on the effectiveness of the passive control systems with added dampers in controlling the response of offshore platforms under a parametric variation of important system parameters and for comparative performance of dampers. Recently, Patil and Jangid (2005) developed passive control systems for vibration control of a certain offshore steel jacket platform using energy dissipation devices such as visco-elastic, viscous and friction dampers.

The horizontal components of earthquake ground motions or ice impacting motions are the most damaging to jacket offshore platforms. There are two primary mechanisms that cause damage. First one is related to inner-storey drifts, defined as the relative displacement between two adjacent floors, and the second one

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concerns with the absolute accelerations as a result of an earthquake or ice-impact. A design concept for reducing both the inner-storey drifts and floor accelerations combines the best aspects of the former two design philosophies. In fact, vibration isolation may have the desired results of reducing both floor accelerations and inner-storey drifts and therefore avoiding permanent damages to the structure itself and protecting what are in the structure. A base isolation system is an important class of passive seismic protective systems and is capable of reducing the horizontal seismic forces transmitted to structures (Tian and Wong, 1990; Wu and Samali, 2002; Woo-Jung et al., 1999). A mid isolation layer setting up between the jacket cap and deck of the offshore platform is capable of reducing the horizontal vibration aroused by ice, earthquake and wave forces. These methods have been successfully used in a practical platform JZ20-2NW. The steel rubber bearing is the most popular type of vibration isolator and is easy to manufacture. It can be made stiff in the vertical direction to take the vertical loads, and flexible in the horizontal direction to isolate the horizontal vibrations. This kind of vibration isolation is very effective in reducing high accelerations, or high frequency motions. The main aim of this isolation system/layer is to shift the natural frequencies of structures to a lower value and then to avoid structural resonance.

Most of the previous experimental investigations and theoretical studies were concentrated in the analysis of dynamic properties, vibration isolation schemes and vibration-reduction effectiveness. Yu and Wang (2005) and Ou et al. (2002) studied vibration-suppressed effectiveness of certain practical jacket platforms which installed both damping isolation systems and steel rubber bearings between the jacket cap and deck. Wu and Samali (2002) and Woo-Jung et al. (1999) analyzed vibration-reduction effectiveness by shaking table test of base isolation models where installed steel rubber bearings between the model structure and ground (shaking table). Liu et al. (2006) have investigated the fatigue characteristics in room temperature. In this paper, experiments on steel rubber bearings were carried out to investigate the compressive properties in different low temperatures and the fatigue property in a certain low temperature range. The results provide some guidance for design of steel rubber vibration isolator used for offshore platforms, and for maintenance and replacement of steel rubber vibration isolator, and a base of fatigue life assessment of the steel rubber vibration isolator using in a cold environment.

2. The principle of vibration isolation and the corresponding isolator

2.1. Theoretical basis of vibration isolation

In practice, it is customary for a continuous structure to be represented by a discrete model of order n, where n is large enough to capture the necessary dynamic characteristics of the structure. Assume that a platform or a structure can be simplified as a lumped mass-spring-isolation layer model of a cantilever structure as shown in Fig. 1. If the problem is linear with non-proportional viscous damping, its motion is governed by the following differential equation.

$$M\ddot{U} + C\dot{U} + KU = F(t) \tag{1}$$

where M, C and K represent the mass, damping and stiffness matrices of size $n \times n$ respectively, and U, $\dot{U}$, $\ddot{U}$ and F represent the displacement, velocity, acceleration and force vectors of order n, respectively.

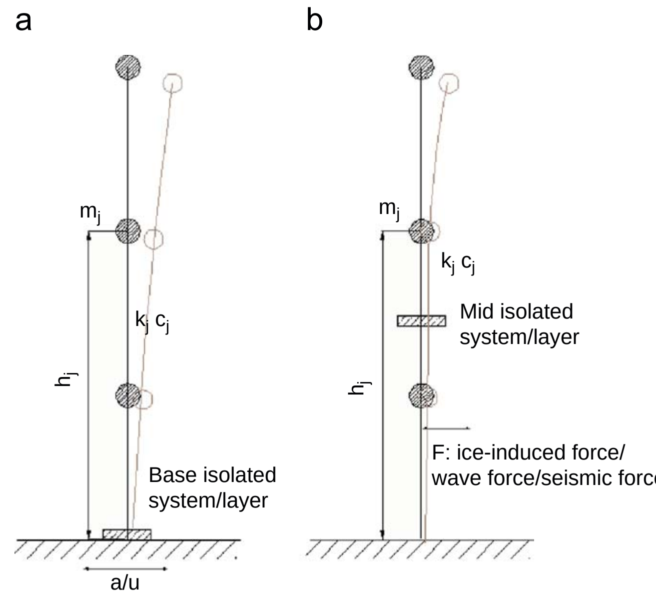

Fig. 1. Simplified isolation model.

The above equation can be written in the form of a state equation as

$$\dot{X} = AX + BF \tag{2}$$

where

$$A = \begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}C \end{bmatrix}, \quad X = \left\{ U^T \quad \dot{U}^T \right\}^T,$$

$$\dot{X} = \left\{ \dot{U}^T \quad \ddot{U}^T \right\}^T, \quad B = \begin{bmatrix} 0 \\ M^{-1} \end{bmatrix} \tag{3}$$

A and X represent, respectively, the system matrix and the state variable vector of order $2n$. By solving the eigen-problem of the system matrix A, then the n pairs of conjugate eigenvalues and eigenvectors of the structural system can be obtained. Further more, by making use of the n nonconjugate eigenvalues and eigenvectors, the following eigenvalue matrix and modal vector matrix can be obtained.

$$\lambda = diag[\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_n], \quad \Phi = [\phi_1, \phi_2, \phi_3, \ldots, \phi_n] \tag{4}$$

where λ_i represents the ith eigenvalue, while ϕ_i represents the natural modal vector with respect to λ_i. Similarly, the two conjugate matrices λ^* and Φ^* can be also determined.

On the other hand, from Eqs. (2) and (3), it is seen that the system matrix A involve the stiffness, damping and mass matrices. M is a determinate matrix and F is the environmental condition. Thus we can adjust A by adjusting stiffness K and damping C to control the motions X and $\dot{X}$, and control the eigenvalues and the natural modal vectors. The corresponding engineering method is to install a damper system or an isolation system/layer. Vibration isolation is a most effective method for the horizontal components of earthquake ground motions or ice impacting/wave force as shown in Fig. 1.

2.2. Specifications and geometrical data of prototype steel rubber bearing

Recently, the use of steel rubber bearing for the vibration isolation of offshore platform has become a common and well recognized method of providing protection against ice-induced, wave force and seismic damage. The geometric layouts of steel rubber bearing used for vibration isolation of offshore jacket