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Friction damper for vibration control in offshore steel jacket platforms

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ABSTRACT

The performance of friction dampers to mitigate the wave-induced vibrations in jacket-type offshore platforms has been investigated in this study. Due to the random nature of ocean waves, a full stochastic analysis method has been used to evaluate the response of the structures equipped with these devices. A stochastic linearization technique has also been used to take the nonlinear behavior of these hysteretic dampers into account. At last, the developed mathematical formulation has been applied to evaluate the response of realistic models, and to find out the optimal values for the adjustable parameters of the friction dampers to dissipate the wave induced vibrations of the platforms.

1. Introduction

In recent decades various types of control schemes have been widely studied and some implemented to improve the dynamic behavior of structures under natural hazards in order to avoid large forces or deflections in excited structures. However, an extensive review of these efforts reported by Spencer and Nagarajaiah [1] shows that most of these researches have focused on the protection of tall buildings and long span bridges against seismic or wind excitations. Only a small part of these researches are related to fixed offshore platforms.

The first group of studies on this topic has been published by Abdel-Rohman [2], who investigated the efficiency of some active and passive control mechanisms to moderate the dynamic response of a steel jacket platform due to wave-induced forces.

In a passive control approach, Hsien Hua Lee [3] utilized viscoelastic dampers as bracings to improve the dynamic performance of an offshore platform and Patil and Jangid [4] have compared the efficiency of viscoelastic, viscous and friction dampers as energy dissipating devices to moderate the dynamic response of steel jacket platforms to sea wave excitations. They have considered an additional stiffness and damping due to the utilization of viscoelastic and viscous dampers, but the way of the inclusion of nonlinear behavior for friction dampers in the spectral analyses of platforms has not been clarified in their published article.

The control mechanism used for fatigue damage mitigation shall interact with the main structure during a considerable part of platform's life span; therefore, implementation of an active control technique with a permanent power source would not be practical in such cases, and, utilizing some kind of passive or semi-active control mechanisms that can be installed on existing platforms are often preferable.

Moreover, considering the excessive cost of underwater fabrication and welding, which obstructs the practical techniques for rehabilitation of offshore platforms; the use of passive control mechanism would be an attractive idea to improve the dynamic behavior of existing offshore platforms.

Utilization of new control mechanisms requires implementing new strategies in the analyses of offshore platforms. One of the most conventional methods for the analysis of offshore structures under random wave's excitation is spectral analysis. Although the spectral analysis approach is more complicated compared to deterministic approach, it yields more realistic and reliable results especially for long-term fatigue analysis, therefore it is recommended in most offshore engineering standards such as API. Linear time invariant response of the structure and zero mean stationary Gaussian random excitation are principal assumptions in this approach, hence the practice of this method for nonlinear structures needs a proper approximating technique such as stochastic linearization [5]. The theoretical basis for this method has firstly been introduced by Booton, Kazakov [6] and Caughey [7] in the 1950s and has found extensive applications in the stochastic analysis of nonlinear dynamic systems. A comprehensive review of the studies on this topic [8] and an introduction to some of its practical applications have been reported by Socha [9]. The stochastic linearization technique exercised in this study relies on the minimization of mean square error which has been first introduced by Atalik and Utku [10].

2. Scope of the current study

The objective of this paper is to evaluate the performance of fixed offshore platforms, utilized with hysteretic damping

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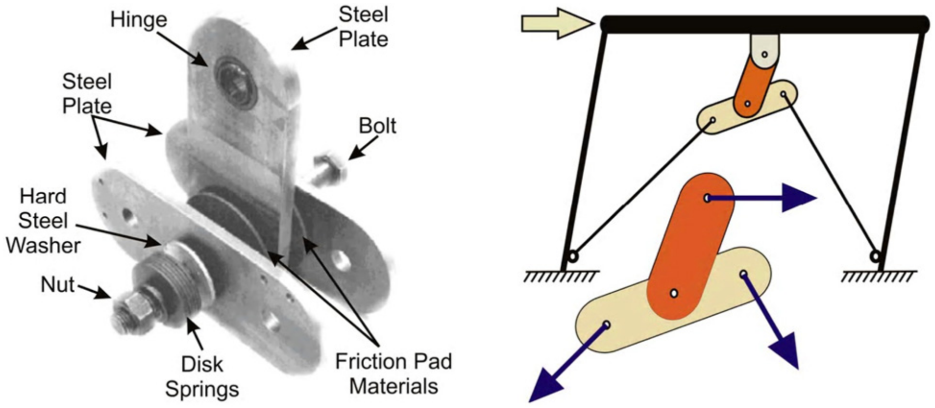

Fig. 1. Configuration of friction damper innovated by Mualla and Belev [11].

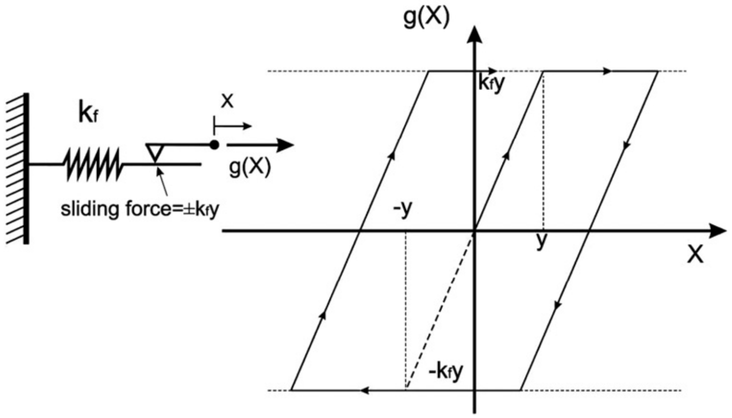

Fig. 2. Force–Deformation diagram for friction damper after Mualla and Belev [11].

device and excited by random wave induced forces. Full stochastic spectral analysis has been used for this purpose and a stochastic linearization method has been employed to take the nonlinear behavior of the hysteretic dampers into consideration. This study has been done with the aim of appreciation of friction dampers, as a passive vibration control device to mitigate the accumulative fatigue damage in steel jacket type platforms. The aim is to find the dependency of dampers' adjustable parameters to the dynamic characteristics of the structure, as well as sea state condition characterized with wave statistic parameters such as significant wave height H_s and mean zero crossing period T_z.

3. Friction dampers

Friction dampers are passive vibration control devices with effective performance in energy dissipation and relatively low cost and ease of installation. The displacement-dependency of energy dissipation rate in friction dampers is the major difference of these devices with other types of dampers. Their resultant damping force is independent of the velocity response of the structure and the frequency content of excitations and this makes them suitable for low frequency excitations such as sea waves loading. Highly nonlinear and force limited action is the dominant characteristic of these devices. Diversiform friction dampers with various configurations have been invented and experimentally tested for passive vibration control applications, with a few practical applications against seismic excitations.

A novel friction damper device, which can be easily installed on existing structures, has been innovated by Mualla and Belev [11], as shown in Fig. 1. They have presented an analytical description of its behavior which follows an idealized hysteretic loop as shown in Fig. 2.

Response spectrum reduction factors which are available in seismic design codes such as FEMA 440, NEHRP 2000 and ATC 40 provide straight methods for consideration of hysteretic devices in the performance-based design of structures. But there is not any standard method for this purpose in the stochastic analysis of structures using the power spectral method.

4. Hysteretic devices under random excitations:

The governing equations of motion for the structure utilized with friction dampers can be derived from the schematic diagram as shown in Fig. 3 and can be written as Eq. (1) in which [M], [C], [K] are the mass, damping and stiffness matrices of the primary structure, respectively.

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}+\{g\}=\{f\} \tag{1}$$

$$[M]=\begin{bmatrix} m_n & 0 & \cdots & 0\\ 0 & m_{n-1} & \cdots & 0\\ \vdots & \vdots & \ddots & 0\\ 0 & 0 & 0 & m_1 \end{bmatrix}$$

$$[K]=\begin{bmatrix} k_n & -k_n & 0 & \cdots & 0 & 0\\ -k_n & k_n+k_{n-1} & -k_{n-1} & \cdots & 0 & 0\\ 0 & -k_{n-1} & k_{n-1}+k_{n-2} & \cdots & 0 & 0\\ \vdots & \vdots & \vdots & \ddots & 0 & 0\\ 0 & 0 & 0 & -k_3 & k_3+k_2 & -k_2\\ 0 & 0 & 0 & 0 & -k_2 & k_2+k_1 \end{bmatrix}$$