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A Hysteretic MDOF Model for Dynamic Analysis of Offshore Towers

P. Paevere
CSIRO BCE/University of Melbourne, Melbourne, Australia

N. Haritos
University of Melbourne, Melbourne, Australia

G.C. Foliente
CSIRO BCE, Melbourne, Australia

ABSTRACT

A lumped mass MDOF model for offshore platforms under extreme deterministic loads is developed. The model includes hysteretic elements that account for highly nonlinear and degrading structural behaviour. Dynamic analyses of an example tower (in still water) are performed using different hysteresis parameters for these elements. It is shown that degrading hysteretic behaviour can cause a significant increase in the variability of the displacement response time history, when compared with elasto-plastic behaviour.

KEY WORDS

hysteretic systems, dynamic analysis, offshore platforms

INTRODUCTION

Offshore structures under severe dynamic excitation may undergo repeated cycles of inelastic deformation. Under such extreme conditions, the load displacement behaviour of the structure is *hysteretic* due to inelastic deformations and/or damping. Depending on the structural material type and configuration, the inelastic response may also be accompanied by strength degradation and/or stiffness degradation and/or pinching of the hysteresis loops. Such degradation may be critical as it can lead to large displacements, weakening or failure of the joints, shifts in frequency of vibration, and perhaps even collapse of the structure.

To satisfactorily design and analyse the behaviour of structures under severe dynamic loads, multi-degree-of-freedom (MDOF) models are required that include hysteretic elements which can produce the true behaviour of the structure at all displacement levels and strain rates (Sozen, 1974). In this paper, a lumped-mass MDOF model for analysis of structures under severe dynamic loadings is presented. The model includes hysteretic elements that account for *highly nonlinear, inelastic behaviour* which are generally applicable to a wide variety of material types and structural configurations (Foliente et al, 1996) . The hysteretic elements are capable of modeling a smooth nonlinear inelastic load-displacement relationship (with or without a distinct yield point), strength degradation, stiffness degradation and pinching.

An example offshore tower is analysed for a range of seismic excitations to demonstrate the model's capability, and the importance of the hysteretic behaviour in reliability analysis. Two different types of hysteretic behaviour are used for each load case: 1) an elasto-plastic non-degrading hysteresis; and 2) a smooth degrading hysteresis. The effect of the local hysteresis behaviour on the global displacement response and the implications for the reliability analysis of such structures are investigated.

HYSTERESIS MODEL FOR DEGRADING PINCHING BEHAVIOUR

Numerous hysteresis models have been proposed [bi-linear, tri-linear, Takeda, Ramberg-Osgood, Clough, Stewart] but many of these are simplistic and limited to specific materials and/or structural configurations. A more general model, referred to herein as the Bouc-Wen-Baber-Noori-Foliente (BWBNF) model has been chosen for this work [Baber and Wen (1981), Foliente (1995), Foliente et. al. (1996)] due to it's versatility and ability to portray complex structural behaviour. The BWBNF model allows for a smoothly varying hysteresis (with or without a distinct yield point) and is capable of reproducing a wide range of shapes. Strength and stiffness degradation behaviour can be included; the level of degradation is a function of the cumulative energy dissipation. Pinching behaviour can also be accounted for using a slip-lock type function which is gradually activated after yielding. Consider a single-degree-of-freedom (SDOF) hysteretic system under forcing function *F(t)* as shown in Fig. 1.

The equation of motion may be generally written as:

$$m\ddot{u} + c\dot{u} + R[u(t), z(t); t] = F(t) \qquad (1)$$

where u is the displacement and the dots represent derivatives with respect to time. The restoring forces acting on the mass m are broken into discrete components. The inertial restoring force is given by $m\ddot{u}$. The damping restoring force is given by $c\dot{u}$ and is assumed linear. The non-damping restoring force is given by $R[u(t), z(t); t]$ and consists of a linear and a hysteretic (nonlinear) component. The linear component is given by αku and the hysteretic component is given by $(1-\alpha)kz$, where α is a weighting constant representing the relative participation