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A simplified ratcheting limit method based on limit analysis using modified yield surface

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ABSTRACT

Two effective approaches for obtaining ratchet boundaries of a structure undergoing cyclic loads are presented. The approaches use limit analysis of a structure whose yield surface is modified according to the cyclic load. In the first approach, Uniform Modified Yield (UMY) surface is used. UMY approach reduces the Mises-based cylindrical yield surface by Mises stress of the cyclic stress amplitude. UMY method was slightly conservative, and sometimes overly conservative, especially at high ratio of cyclic load to primary steady load. Conservatism, caused by the assumption that the modified yield surface remains isotropic, is eliminated by considering anisotropic Load Dependent Yield Modification approach, LDYM. This approach reduces yield strength based on relative orientation of steady primary and cyclic stress tensors. This work assumed elastic perfect plastic material behavior, with no strain hardening for both original and modified yield surfaces. Ratchet boundaries of several structures, published in literature, were obtained using UMY and LDYM approaches and verified against published data and results of conventional methods. Numerical procedures for UMY and LDYM approaches are extremely fast relative to conventional numerical schemes, and are not restricted by complex geometry or loading.

1. Introduction

The necessary theoretical developments for bounding solutions of cyclic analysis of structures under cyclic loads were developed quite some time ago, specifically shakedown theory. Gokhfeld provides an excellent summary of the history of the development of shakedown theory [1,2]. Gokhfeld points out that Koiter was the first to recognize that theorems on plastic collapse of structures were limiting cases of the shakedown theorems. Koiter's kinematic theorem and several restatements of Melan's static theorem led to Gokhfeld's concept of a fictitious yield surface; this led to the reduction of the shakedown and ratcheting problems to a limit analysis problem for a body possessing inhomogeneous fictitious strength properties. Gokhfeld also developed a ratcheting theory proof, incorporating Koiter's kinematic shakedown theory; this proof completed the fundamental theoretical basis for cyclic analysis of structures [1,2]. Gokhfeld's fictitious yield surface technique utilizes an approach where cyclic loads reduce the ability of a structure to resist constant primary loads. The original yield surface is modified according to the reduction in resistance to load carrying capacity to obtain a fictitious yield surface. Subsequent limit analysis of the heterogeneous structure permits categorization of structural behavior. The advantages of the technique lie in the potential of providing significant cost and time savings in conducting analyses than the other conventional techniques such as inelastic cyclic analysis whereby the behavior of the structure is numerically predicted by complex simulations such as finite element methods.

In the last decade or two, implementation of these proofs in predicting the response of structures was limited to classes of structures and loading that permitted analytical, closed form solutions to be developed. This limitation was due to the difficulty associated with solving differential equations for equilibrium and compatibility for discrete points of structures. The shakedown problem was later discretized and the equations of equilibrium and compatibility reformulated with linear algebraic equations; this enabled solutions for the shakedown and ratcheting problems to be achieved with linear programming [1,2]. Ponter was instrumental in the development and application of linear programming solutions to shakedown problems, although others have utilized similar approaches to solve inelastic problems [2–20]. The challenge in cyclic design analysis today lies in simplified integration of the shakedown and ratcheting bounding theorems with modern computational tools without losing generality of the fundamentals of the problem.

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