A plain linear rule for fatigue analysis under natural loading considering the sequence effect'

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Abstract

Fatigue under variable amplitude loading is currently assessed with the Palmgren-Miner rule in structural standards, ignoring the order of loading, which would require non-linear or mixed rules, especially for the random loading sequences applied to certain structures. Therefore, the goal is to develop a practical and simple correction factor ensuring the linear summation of damage is conservative, so as to take the sequence effect into account in random loading from natural sources. The theoretical consistency of this approach is demonstrated and a case study is developed to test the feasibility of the new rule and its simplicity.

Keywords: cumulative damage, variable amplitude fatigue, damage accumulation, sequence effect, random loading.

1 Introduction

It is well known in the literature that the sequential order of cycles is an important factor [1, 2, 3, 4, 5, 6, 7, 8] when assessing total cumulative fatigue damage. In fact, for certain sets of cycles, when larger ranges are applied beforehand, the resulting fatigue damage accumulation is higher, while precisely the opposite holds true in other cases [9, 10, 11, 12]: an aspect that will be explained in §2. However, simple linear approximations, such as the widely used Palmgren-Miner rule [13, 14], despite their practical and easy application, are unable to consider this effect [8, 15]. So, consideration of the sequence effect will require a more complex and therefore less practical non-linear rule [1, 2, 8, 15, 16]: as detailed in §3. Logically, the question arises of how to predict complex random loading from natural sources, i.e. wind, waves, seismic events, human-induced vibrations, etc., with disordered cycles of varying ranges, normally studied as stationary and ergodic processes. In such cases, the use of a non-linear rule for cumulative fatigue damage could be more accurate, but also more time intensive and of greater difficulty. In common structural elements and Eurocode design calculations [17, 18, 19] or equivalent structural standards, the real added value of a rule is its simplicity coupled with accuracy and safety [7]. These are the main advantages that justify why the Palmgren-Miner [13, 14] rule is still specified in these standards: although not more accurate, it is very practical, so the goal is to develop a practical correction factor ensuring the linear summation of damage is conservative. Following this acknowledged line of reasoning in engineering, a plain