SHAKEDOWN ANALYSIS OF ELASTOPLASTIC STRUCTURES: A REVIEW OF RECENT DEVELOPMENTS

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SUMMARY

Many structures and structural elements are exposed to loads and/or other external actions (such as temperature changes and radiation) which vary significantly and repeatedly in time and may produce inelastic deformations. These circumstances occur in various technological areas, but are particularly frequent and important in nuclear technology. Since many years several theorems and methods are available for predicting whether an elastoplastic system subject to variable repeated straining effects will shakedown; otherwise, it will eventually undergo failure by incremental collapse or alternating plasticity ("low cycle fatigue"). In the last decade the classical shakedown theory was considerably enriched by new results at the levels of basic principles, solutions of special cases and general numerical techniques.

This survey aims at outlining in a unitary frame most of these recent developments alone (so that it is intended as supplementary to the survey paper presented at the 2nd SMiRT by A. Sawczuk). Emphasis will be on those results which are of particular interest in nuclear reactor technology.

Some of the developments to be considered were originally carried out by the classical continuum approach; others by means of discrete (such as finite element) structural models which, however, provide an almost necessary basis for numerical solutions of real-life problems. Therefore both approaches and the relevant notations are taken into consideration in the paper.

The first set of results covered, concerns shakedown in the presence of dynamic effects (significant inertia and, possibly, viscous damping forces). Allowance is also made for a limited but meaningful class of hardening rules and of second order geometric effects. The relevant generalizations of the classical theorems by Melan-Bleich and Koiter are described. Further extensions to nonassociated flow laws are mentioned. Mathematical programming techniques for the evaluation of the safety factor are discussed.

A second group of results concerns structures subjected to variable thermal loading, with temperature-dependent material properties (yield limits, elastic moduli). In this new context the basic shakedown theorems are re-stated and solution methods are pointed out, which were successfully applied to some simple practical problems (thickwalled cylinders, turbine rotating disks).

It is clearly important in practice to assess at least the order of magnitude of some meaningful displacement and/or intrinsic deformation, even shakedown is ascertained. In fact, excessive deflections can mean inserviceability of the structure or lack of validity of the shakedown theory (based on geometric linearity); excessive strains may imply local failure. Upper bounds on deformation parameters are discussed as third main subject of the survey, account taken of inertia forces, thermal and geometric effects. Some numerical experience, based on mathematical programming and concerning frame-like structures, is referred to, for comparative assessment of merits of various bounding techniques.

Some particular though by no means less important results are briefly mentioned, such those concerning rigid-hardening material models, time-dependent (creep) effects on shakedown, the use of optimal control methods, optimum (minimum weight) design under shakedown behavior constraints. Some still open theoretical problems and prospects of future research, especially those relevant to nuclear engineering, are pointed out at the end.