A Simplified Technique for Determination of Shakedown Loads for Structures under Cyclic Loading

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When critical structures are subjected to combined steady and cyclic loads, design is usually made on the basis of elastic shakedown. Operation under shakedown conditions gives much larger load domains than design on the basis of purely elastic behavior. Under shakedown conditions, small plasticity is permitted to develop during the early load cycles, but subsequent steady state behavior is purely elastic. **Design** using shakedown concept ensures that the following two modes of failure are avoided:

- Incremental collapse or ratcheting mode of failure, in which the structure suffers from accumulation of small plastic deformation each load cycle, leading eventually to exhaustion of material ductility
- Low cycle fatigue in which regions of stress concentration experience repeated reversed plastic strain cycle which leads to failure by fatigue after a certain number of cycles.

Joint research work aiming at development of an efficient and reliable simplified numerical technique for determination of shakedown load has been conducted during the last 5 years by a combined team of Cairo University (**M. M. Megahed**) and the American University in Cairo (**H.F. Abdalla, and M.Y.A. Younan**). Results of this research effort is documented in a number of publications; from which two papers have enjoyed international recognition as follows:

- H.F. Abdalla, M. M. Megahed, and M.Y.A. Younan, Determination of Shakedown 90-degree Pipe Bend Using A Simplified Technique, ASME J. PV Technology, Vol. 128, No.4, pp. 618-624, 2006 **(Winner of Editors Choice Award-2006)**
- H.F. Abdalla, M. M. Megahed, and M.Y.A. Younan, A Simplified Technique for Shakedown Load Limit Load Determination, Journal of Nuclear Engineering and Design, Vol 237, pp. 1231-1240, 2007 **(Winner of Jaeger Prize SMIRT-18)**

The simplified technique was initially validated against the analytical solutions of three benchmark problems namely: a two-bar structure subjected to steady axial force and cyclic thermal loading, a thin-walled tube subjected to steady internal pressure and cyclic high thermal fluxes across its wall, and a large thin square plate with a small central hole subjected to cyclic biaxial tensile loads along its edges. The simplified technique outcomes showed excellent correlation with the analytically determined solutions of the three benchmark problems.

The technique is then extensily applied to determination of shakedown loads for pipe bends subjected to steady internal pressures and cyclic bending loadings. The cyclic loading includes three different bending patterns namely; in-plane closing (IPC), in-plane opening (IPO), and out-of-plane (OP) bending loadings. Behavior of pipe bends under cyclic loading is important in piping work of power stations and nuclear reactors in particular. Results of the technique correlated very well with recent experimental test results on ratchetting of low-carbon steel 90-degree pipe bend subjected to cyclic reversed in-plane bending force in addition to internal pressure.

Due to the superiority of the technique over other calculation routes, the need arises to continue its improvement and refinement and further verification through the following steps:

- Application of the the technique to other structures and mechanical components of practical interest such as nozzles in cylinderical and spherical pressure vessels, pipe branches, ... etc.

Conducting laboratory tests to simulate cyclic elasto-plastic behavior of pipe bends and/or other components particularly at low pressures, at which the boundary between shakedown and fatigue applies.