Evaluation and Validation of the Vibration Correlation Technique (VCT) for Predicting Buckling Loads and Diagnosing Degradation of Thin-Walled Structures

The Vibration Correlation Technique (VCT) is a nondestructive experimental method used to assess the buckling loads of thin-walled structures. A buckling load should be understood as the load that causes the loss of stability of the tested object. The VCT involves measuring the natural frequencies of the tested object and recording the change in these frequencies as the load increases. Assuming that the vibration modes are similar to the buckling modes, one can draw a curve showing the variability of the dimensionless frequency versus the applied load, and extrapolating this curve to zero allows for predicting the buckling load of the tested structure. The problem, however, lies in the fact that each basic type of structure, such as a beam, plate, column, panel, or shell, requires the construction of a different characteristic curve from which the buckling load prediction is derived. For thin-walled columns and beams, existing mathematical descriptions are insufficient. These mainly allow for the prediction of global buckling loads, which is adequate for structures with high slenderness, while shorter profiles can also experience local, local-distortional, distortional, and flexural-torsional buckling. These types of buckling in thin-walled profiles do not have their characteristic curves. This issue is significant for isotropic structures, and in the case of fiber composites, existing solutions are usually limited to cases of symmetric laminates. In the proposed research, several loading schemes will be analyzed, such as compression, eccentric compression, pure bending, and bending with torsion. In the case of compression and bending, it is also planned to introduce local degradation due to low-velocity impact and to verify whether the VCT is applicable in such cases and whether it can identify internal material degradation that cannot be diagnosed solely based on structural response. The project's objective is the evaluation and validation of the VCT for predicting buckling loads and diagnosing degradation of thin-walled structures. This objective will be achieved through the creation of original numerical models using the boundary element method, commercial software based on the finite element method (ANSYS and LS-Dyna), analytical methods, and a series of experimental studies. The project aims to answer the following questions: How effectively does the VCT predict buckling loads in different loading scenarios for thin-walled structures? Can the VCT be used to diagnose degradation caused by impacts by comparing frequency response to the response recorded at the beginning of the operational period? What are the differences in predicting buckling loads between isotropic and composite materials? And what modifications to classical characteristic plots are needed to improve the accuracy of predicting buckling loads using VCT, and what new characteristic plots will enable effective prediction of buckling loads? The project aims not only to confirm the effectiveness of the VCT in predicting buckling loads but also to develop this method as a diagnostic tool for monitoring the degradation of thin-walled structures under various operational conditions. There is a need to develop reliable methods for predicting buckling loads and detecting early stages of degradation in thin-walled structures. The undertaken research has significant implications for safety and efficiency in engineering. Buckling is one of the main causes of failure in thin-walled structures. It is important to emphasize that through research on reliable techniques for predicting buckling loads, such as VCT, existing structural materials can be used more efficiently. Designed structures can be lighter and more economical while still meeting safety standards and strength requirements. It should also be noted that the achieved experimental results regarding buckling phenomena form the basis for developing standards and recommending best practices to engineers. The results of the planned research will significantly expand our knowledge in the fields of strength and stability of thin-walled structures, as well as in defect tolerance issues of composite materials. The development of analytical, analytical-numerical, and numerical models, as well as characteristic plots that accurately predict the buckling load across a wide range of considered loads, should also be recognized as a valuable contribution to the fields of solid mechanics, computational engineering, and computer-aided modeling. By definition, VCT is an experimental technique that excels at detecting the smallest differences in the boundary conditions of tested objects. Therefore, the expansion of the results database for non-trivial loading cases enhances the confidence of the scientific community and the industrial sector in the universal applicability of the VCT in nondestructive testing.