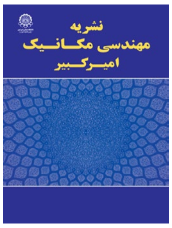

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(1) (2020) 55-58
DOI: 10.22060/mej.2018.14754.5931

Prediction of the Critical Buckling Load of Grid-Stiffened Composite Plates Using Vibration Correlation Technique

D. Shahgholian-Ghahfarokhi, M. Aghaei-Ruzbahani, G. H. Rahimi*

Department of Mechanical Engineering, Tarbiat Modares University, Tehran, Iran

ABSTRACT: Due to unique properties, grid-stiffened composite plates are used extensively in aviation, marine and automotive industry. In recent decades, several studies are done to predict the critical buckling load of grid-stiffened composite plates without breakdown or failure. One of the most important non-destructive methods, is vibration correlation technique. The aim of this research is the prediction of the critical buckling load of grid-stiffened composite plates using vibration correlation technique. For this purpose, nonlinear vibration analysis of grid-stiffened composite plates is firstly performed in different compressive loads using finite element software ABAQUS. In the next step, critical buckling load of grid stiffened composite cylinder shells is predicted using vibration correlation technique. To validate the results of vibration correlation technique, three grid-stiffened composite plates are fabricated using filament winding and hand lay-up method with same conditions and was placed under axial compression test. Finally, the critical buckling load is measured experimentally. The results show that the difference between the critical buckling load of vibration correlation technique with experimental buckling load is less than 5%. This subject implies that vibration correlation technique is suitable for prediction of critical buckling load of grid-stiffened composite plates with very high accuracy.

Review History:

Received: 26 Jul. 2018
Revised: 6 Oct. 2018
Accepted: 10 Nov. 2018
Available Online: 20 Nov. 2018

Keywords:

Grid-stiffened composite plates
Vibration correlation technique
Buckling
Fabrication
Numerical analysis

1- Introduction

Due to the advancement of industry and technology and need to structures with high strength and stiffness while having low weight, the grid-stiffened composite plates are used extensively in aviation, marine and automotive industry. Since that these plates are thin, and generally are under axial load or external pressure, the buckling analysis is very important and one of the most important failure modes. There are several methods for calculating the buckling load of different structures. One of the most important nondestructive methods is the Vibration Correlation Technique (VCT). This technique can determine the buckling load for several types of structures without reaching the instability point. The concept of VCT is usually based on an experimentally determined functional form of the vibration frequency variation with the applied load that is fitted to the test data and extrapolated to estimate the critical buckling load, without actually reaching the instability point.

The first study on the VCT was carried out in the 20th century. A detailed review of the VCT approach can be seen in Chapter 15 of refrence [1]. The buckling load of composite panels was obtained using VCT by Abramovich et al. [2]. Jansen et al. [3] presented a modified VCT, which are accounted for the geometrical imperfections in the analysis. Based on the Souza method presented in the [4], a new VCT was presented by Arbelo at al. [5]. Kalnins et al. [6] estimated the buckling load of un-stiffened cylindrical shells using VCT. Chaves-Vargas et al. [7] predicted the buckling load of the CFRP stiffened plate. Skukis et al. [8] showed that the proposed approach has a good correlation when the maximum load is higher than 65% of the buckling load obtained in testing phases. Shahgholian-Ghahfarokhi et al. [9] predicted the buckling load of composite cylindrical shells by using VCT. It was shown that maximum error is less than 3%.

The main purpose of the present paper is calculating the critical buckling load of grid-stiffened composite plates using VCT. For this purpose, nonlinear vibration analysis of grid-stiffened composite plates is firstly performed in different compressive loads using finite element software ABAQUS. Then, natural frequencies are extracted. In the next step, critical buckling load of grid stiffened composite cylinder shells is predicted using VCT. Finally, three grid-stiffened composite plates are fabricated using filament winding and hand lay-up method with same conditions and were placed under axial compression test to validate the results of VCT.

2- Finite Element Analysis

As shown in Fig. 1 and Table 1, H2 and H3 are heights of the DaTo calculate the natural frequency of grid-stiffened composite plates, a finite element analysis is performed using ABAQUS CAE software. The specimens are considered grid-stiffened composite plates with the triangle grid in the present paper. This structure is fabricated from one skin and stiffeners. The length, width, and thickness of the skin are 300, 140 and 1.75 mm, respectively. Also, the length and width of the stiffeners are 3 mm. The skin is fabricated from glass woven fabric with a density of 200 gr/m2 and room-temperature-curing epoxy

*Corresponding author's email: rahimi_gh@modares.ac.ir

matrix. Also, stiffeners are fabricated from E-glass fibers with density 2.4 gr/m, and room-temperature-curing epoxy matrix. By performing tests according to ASTM D3039M and using the micromechanical approach, the mechanical properties are obtained, and listed in Table 1. The skin and stiffeners have been meshed using the quadratic planar elements with 4 nodes (S4R) and brick elements with reduced integration with 20 nodes (C3D20R), respectively. The optimal number elements of the sandwich plate were obtained at 22680, after a convergence study.

Table 1. Material properties skin and stiffeners

Property		Skin	Stiffeners
Young's Modulus (GPa)	E_1	17.75	13.78
	$E_2=E_3$	5.11	4.54
Shear Modulus (GPa)	$G_{12}=G_{13}$	1.6	1.67
	G_{23}	2.36	3.49
Poisson's ratio	$\upsilon_{12}=\upsilon_{13}$	0.278	0.285
	υ_{23}	0.0854	0.135

3- Specimens Manufacturing

To fabricate the specimens, the filament winding and hand lay-up method are used for stiffeners and skin. After the fabrication of the skin and stiffeners, any two parts are stuck together. The fabricated grid-stiffened composite plates are shown in Fig. 1.

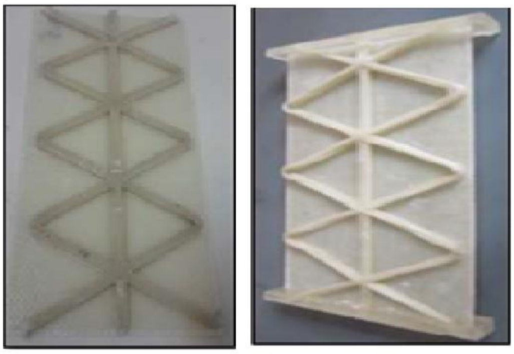

Fig. 1. The fabricated specimens

4- The VCT Implementation

In order to predict the critical buckling load of the grid-stiffened composite plates, linear and nonlinear critical buckling load of the stiffened plates (Plinear and Pnonlinear) are calculated. Then, the variations of the natural frequency with the applied load are recorded while the applied load is increased. The knockdown factor (ξ2), the ratio of buckling loads of imperfect, and perfect plate, are extracted from the natural frequencies squared vs. applied load graph. The plot of second order curve fitting (1-P)2 versus (1- f2) is shown in Fig. 2. The minimum value of this graph is the knockdown factor as shown in Fig. 2. Finally, the critical buckling load can be calculated by Eq. (1).

$$P_{\mathrm{VCT}} = P_{\mathrm{VCT}}(1-\sqrt{\xi^2}) \quad (1)$$

5- Results

The linear buckling loads are listed in Table 2. The nonlinear

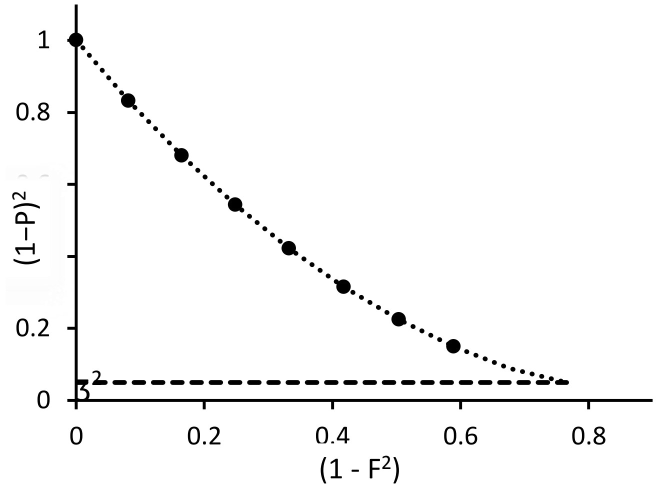

Fig. 2. The plot of (1-P)^2 versus (1- f^2)

Table 2. Linear buckling load

Mode	1st	2nd	3rd	4th
Buckling load (kN)	1.71	3.19	4.11	4.80

frequencies at different levels of the applied compressive load are seen in Fig. 3. As per obtained nonlinear frequencies in Fig. 3 and using Eq. (1), the buckling load prediction using the VCT approach is obtained 1.42 kN.

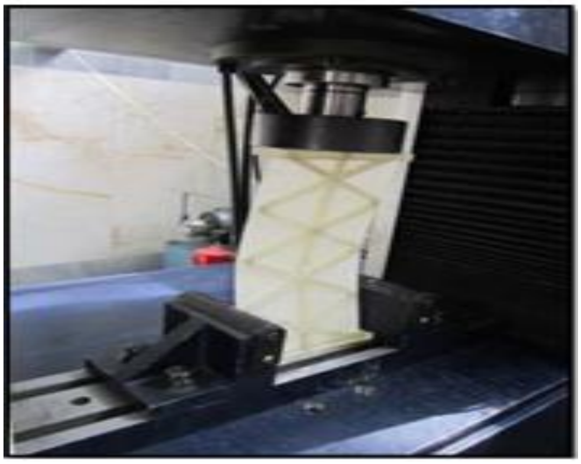

Fig. 3. The experimental buckling test

To validate VCT results, the experimental buckling load (PEXP) is obtained from the buckling test as shown in Fig. 4. This test repeated for four specimens. The experimental buckling load (PEXP), the predicted buckling load using the VCT (PVCT), and linear and nonlinear buckling load are given in Table 3.

Table 3. Buckling load results

	P_{EXP}	P_{linear}	$P_{\mathrm{nonlinear}}$	P_{VCT}
Buckling load (kN)	1.48	1.71	1.57	1.42

6- Conclusions

The main conclusions are as below:

1- The difference between the predicted buckling load using the VCT approach with an experimental buckling load is less than 2.1% when the maximum applied load is less than 80% of the buckling load.

2- The VCT approach has an acceptable estimation for grid-stiffened plates until the maximum applied load is higher than 45% of the experimental buckling load.

References

[1] J. Singer, J. Arbocz, T. Weller, Buckling experiments, shells, built-up structures, composites and additional topics, John Wiley & Sons, 1998.

[2] H. Abramovich, D. Govich, A. Grunwald, Buckling prediction of panels using the vibration correlation technique, Progress in Aerospace Sciences, 78 (2015) 62-73.

[3] E. Jansen, H. Abramovich, R. Rolfes, The direct prediction of buckling loads of shells under axial compression using VCT—towards an upgraded approach, in: Proceedings of the 27th Congress of the International Council of the Aeronautical Sciences, 2014.

[4] M. Souza, L. Assaid, A new technique for the prediction of buckling loads from nondestructive vibration tests, Experimental Mechanics, 31(2) (1991) 93-97.

[5] M.A. Arbelo, K. Kalnins, O. Ozolins, E. Skukis, S.G. Castro, R. Degenhardt, Experimental and numerical estimation of buckling load on unstiffened cylindrical shells using a vibration correlation technique, Thin-Walled Structures, 94 (2015) 273-279.

[6] K. Kalnins, M.A. Arbelo, O. Ozolins, E. Skukis, S.G. Castro, R. Degenhardt, Experimental nondestructive test for estimation of buckling load on unstiffened cylindrical shells using vibration correlation technique, Shock and Vibration, 2015 (2015).

[7] M. Chaves-Vargas, A. Dafnis, H.-G. Reimerdes, K.-U. Schröder, Modal parameter identification of a compression-loaded CFRP stiffened plate and correlation with its buckling behaviour, Progress in Aerospace Sciences, 78 (2015) 39-49.

[8] E. Skukis, O. Ozolins, K. Kalnins, M.A. Arbelo, Experimental test for estimation of buckling load on unstiffened cylindrical shells by vibration correlation technique, Procedia Engineering, 172 (2017) 1023-1030.

[9] D. Shahgholian-Ghahfarokhi, M.-R. Raafat, G.-H. Rahimi, Prediction of the critical buckling load of composite cylindrical shells by using Vibration Correlation Technique, Journal of Science and Technology of Composites, 5 (2016) 120-130.(In persian)