# Dynamics of sandwich plates weakened by single/multiple debonding

Vyacheslav N. Burlayenko[1] and Tomasz Sadowski[2]*

[1]*Department of Applied Mathematics, National Technical University 'KhPI'*
*ul. Frunze 21, 61002 Kharkov, Ukraine*
*e-mail: burlayenko@kpi.kharkov.ua*

[2]*Chair of Department of Solid Mechanics, Lublin University of Technology*
*ul. Nadbystrzycka 40, 20-618 Lublin, Poland*
*e-mail: t.sadowski@pollub.pl*

**Abstract**

The dynamic behavior of partially damaged at the skin/core interface sandwich plates with flexible honeycomb and polyvinyl chloride (PVC) foam cores are studied. The commercial finite element code ABAQUS is used to calculate natural frequencies and mode shapes of the sandwich plates with the debond zone. The effects of debonding size, debonding location and number of debonding on the modal parameters of damaged sandwich plates with various boundary conditions are investigated. The results of dynamic analysis illustrated that can be useful for analyzing practical problems related to the non-destructive damage detection of delaminated sandwich plates.

*Keywords: debonding, sandwich plates, FE dynamics predictions*

## 1. Introduction

Debonding is one of the most severe defects associated with sandwich composite structures [1]. It may be caused by imperfections of manufacturing processes or by impact events as well as aggressive environmental and loading conditions during in-service lifetime. The damage inflicted by debonding may lead to the significant degradation of the load carrying capacity of sandwich structures and affects their mechanical behaviour. Due to that the debonding is identified as a pre-failure mode of sandwich construction elements that determines integrity and safety of a whole construction. Therefore, debonding must be detected immediately after its occurrence.

There are many current methods to identify structural damage state of structures such as X-rays, acoustic or thermal radiation and so on [2]. However, they often fail to detect the debonded interface region due to large differences between properties of the core and skin materials. The non-destructive testing approaches based on data from structural vibration responses are very attractive for diagnosing and detecting the location and severity of damage in sandwich structures [3]. Finite element method is a powerful engineering tool that can be alternatively used along with complex and expensive experiments for acquisition of the structural vibration responses of structures with damage. Therefore, to establish an accurate and efficient dynamics model for a sandwich structure containing debonding is an important precondition in the context of the health monitoring and damage detection of sandwich structures.

## 2. Modelling

In the present study, the free vibration analysis of sandwich plates with honeycomb and PVC foam cores containing debonding is performed. Dynamic characteristics such as natural frequencies and corresponding mode shapes of the intact and debonded sandwich plates are calculated using the commercial finite element code ABAQUS/Standard v. 6.6 [4].

### 2.1. Materials

The homogenisation technique is used to treat the honeycomb as a homogeneous orthotropic material with equivalent material constants and density. For this purpose the finite element approach based on the unit cell conception [5] was applied. The cores made of PVC foam of various densities are considered as a homogeneous isotropic material with data given by manufacturer in [6].

### 2.2. FE meshing

Based on the shell-to-solid coupling, the present three-dimensional FE models of the sandwich plates include continuum shell elements for modeling the skins and solid elements with incompatible mode for discretization of the core. Debonding is modeled as an artificial flaw embedded into interface between the skin and the core of the sandwich plates. The possible debonded region is known a prior and is assumed to exist before the vibration starts and to be constant during oscillations. Regular shape such as circle or rectangle idealizes an arbitrary debonding shape.

The debonded region is modeled by creating a small gap between the face sheet and the core. To prevent the debonded face sheet from overlapping with the core and to model opening and closing behavior of the interfacial damage in the vibrating

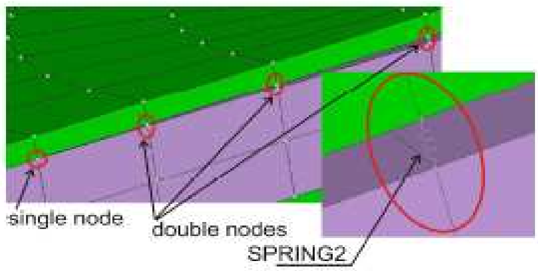


Figure 1: Finite element mesh detail in the debonded zone

* Financial support of Structural Funds in the **Operational Programme - Innovative Economy (IE OP)** financed from the European Regional Development Fund - Project No POIG.0101.02-00-015/08 is gratefully acknowledged.

state, 3D spring elements were introduced between nodes of the debonded region (Figure 1). The spring stiffness was taken as an arbitrary value between zero in the tension and very big stiffness in compression when relative transverse displacement goes to zero. Because the influence of the friction properties on the dynamic responses is negligible, the contact friction was assumed as equal to zero.

## 3. Numerical results

The numerical results of the FE analyses were obtained to provide insight and understanding of the effects of number and placement of debonding on natural frequencies and corresponding mode shapes of sandwich plates partially damaged at the skin/core interface. The influence of boundary conditions and core types on the dynamic responses is also studied. Effects of debonding on vibration responses of damaged sandwich plates were assessed by comparing numerical results of free vibration analysis between intact plates and plates with single/multiple debonding.

### *3.1. Convergence study*

A convergence study was carried out to obtain values of natural frequencies as accurately as possible at the minimum number of elements required with the view to optimize computational time. A honeycomb sandwich beam with rectangular cross-section damaged at the middle span is used for this purpose. The experimental data of the five first modes of this sandwich beam were obtained in [7] and, thereby, were used to compare against the numerical calculations performed with ABAQUS.

### *3.2. Effect of debonding number and placement*

The effects of number and placement of debonding on natural frequencies as well as corresponding mode shapes are investigated. Effects of debonding on vibration responses of damaged sandwich plates is studied by comparing numerical results of free vibration analysis between intact plates and plates with single/multiple debonding.

Parametric studies over a range of size, location and number of debonding zones to obtain the influence of these parameters on the overall dynamic behavior of the damaged plates are performed. As a consequence, natural frequencies and mode shapes were calculated as a function of these parameters and some conclusions concerning the debonding presence could be drawn.

The numerical results, in general, demonstrated that a local damage at the interface of the sandwich plates leads to the significant shift and reduction in natural frequencies and their corresponding modes and the higher natural frequencies are more sensitive to the debonding presence. Moreover, the numerical results also showed that the natural frequencies decrease with increase of debonding size and it is greatly dependent on the boundary conditions.

Finally, sandwich plates with single debonding of arbitrary in-plane placement (centrally and corner located), and with two debondings equal sized symmetrically located at the given boundary conditions were investigated. Thus, differences in mode shape patterns between plates due to debonding presence were observed. It is important to note that the most differences were revealed for case when there were multiple debondings.

### *3.3. Application to non-destructive testing*

The results reported above can be especially useful in providing a way of non-destructive detection and evaluation debonding in sandwich plates using the Cawley-Adams criterion [8]. The presence of damage is indicated immediately from changes in the natural frequencies. Location and severity of damage can be assessed using sensitivity of natural frequencies to changes in the stiffness of a structure that is calculated from the mode shapes of healthy and damaged structures.

## 4. Conclusions

Conclusive points from these investigations are the following:

- size of the debonding zone strongly influences the sandwich plates response. The natural frequencies of debonded plates decrease due to loss in stiffness caused by existence of initial discontinuity. The mode shapes contain local deformations in the region of discontinuity. The influence of debonding becomes more visible with increasing size of the discontinuity zone,
- boundary conditions imposed on oscillated sandwich plate are very important. The results indicate that the more strongly the plate is restrained, the greater the shift of fundamental frequencies for the given debonding size,
- core types of the sandwich plates strongly affect the dynamic structure responses. Soft core made of light PVC foams is less sensitive for shifting of natural frequencies due to debonding presence while heavy PVC foams making the whole sandwich structure stiffer increase the frequency shift However, the numerical results for honeycomb sandwich plate (much rigid in comparison to both previous cases) indicate that the response of stiff structure is significantly different, ,
- higher natural frequencies and mode shapes are more sensitive to the debonding presence,
- the most differences of the dynamic responses between healthy plate and plate containing debonding have been revealed for case when multiple zones of debonding were existed.

## References

[1] Tomblin, J., Lacy, T., Smith, B., Hooper, S., Vizzini A. and Lee, S., Review of damage tolerance for composite sandwich aircraft structures, *Technical report DOT/FAA/AR-99/49*, Office of Aviation Research, Washington, DC 20591, 1999.

[2] Van der Auweraer, H., International research projects on structural damage detection, *Damage Assessment of Structures Key Engineering Materials*, Vol. 204**(**2), pp. 97-112, 2001.

[3] Carden, E.P. and Fanning, P., Vibration based condition monitoring: A review, *Structural Health Monitoring*, Vol. 3 (4), pp. 355-377, 2004.

[4] *ABAQUS User Manual, Version 6.6*, ABAQUS Inc., Pawtucket, Rhode Island, USA, 2006.

[5] Grediac, M., A finite element study of the transverse shear in honeycomb cores, *International Journal Solids and Structures*, Vol. 30(13), pp. 1777-1788, 1993.

[6] DIAB International AB, *Divinycell H: Technical Manual*, Eastville Close, Gloucester, 2007.

[7] Frostig, Y., Behaviour of delaminated sandwich beam with transversely exible core – high oreder theory, *Composite Structures*, Vol. 20, pp. 1-16, 1992.

[8] Cawley, P. and Adams, R.D., The location of defects in structures from measurements of natural frequencies, *Journal of Strain Analysis*, Vol. 14(2), pp. 49-57, 1979.