

Analysis of Dynamic Instability in Sandwich Thick Beams with Flexible Functional Core Subjected to a Follower Force

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ABSTRACT: Aerial structures under non-conservative forces especially follower loads, may be exposed to dynamic or static instabilities. Thus, it is essential to design these structures so that it would prevent this phenomenon. In this paper, for the first time, dynamic instability of a thick sandwich beam with a flexible core under the follower force is considered using the high-order theory of sandwich beams. In the present paper, shear and normal core plate stresses are also considered, which have been ignored in higher-order sandwich panel theory and improved higher-order sandwich panel theory. The sandwich beam consists of two surfaces and a flexible core. The common surface of the core with the surfaces comprises a complete connection, capable of withstanding shear and vertical stresses. The sandwich beam is considered as a linear elastic structure with small rotations and deformations. Equations of motion of high-order sandwich beams under follower force are derived using Hamilton's principle. The Beam fluttering phenomenon is investigated by applying boundary conditions and using a generalized differential quadrature method. In addition to the verification of results, effects of the beam's geometry and mechanical parameters have been studied. These results revealed that the threshold flutter force of the sandwich beam is similar to Timoshenko one.

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1. INTRODUCTION

Investigating the behavior and dynamic stability of structures under the influence of the follower force is a topic of interest for many researchers. For the first time, the problem of elastic structure stability under the influence of the follower force was studied by Nikolai [1]. Investigation of the follower forces in structures has become of serious interest for researchers when three classic problems were simultaneously stated by Beck, Leipzig, and Hager, which became well-known under their own names. So far, few studies have been performed on the dynamic stability of sandwich structures influenced by follower forces and the behavior of sandwich structures with a targeted flexible core under the traction forces has not yet been investigated. In this paper, for the first time and using the Improved Higher-order Sandwich Panel Theory (IHSAPT) [2], we investigate the dynamic instability and probability of fluttering phenomenon in thick sandwich cantilever beam under compressive follower force.

2. METHODOLOGY

The three-layer higher-order theory used in the present paper is a polynomial model based on the distribution of core movements in terms of thickness, which is based on the results of first Frostig's model, except that the polynomial coefficients are considered unknown. The mathematical formulation of the higher-order sandwich panel theory for

unidirectional panels and sheets is available in Refs. [3-5]. The sandwich beam is considered linear elastic with small displacements and consists of a core with two thin beams and bending rigidity. The core surface is in full connection with the thin beams capable of withstanding shear and vertical stresses. The external load can also be applied to the upper or lower surfaces. Fig. 1 shows the structure of the beam.

Using the first order of the shear theory, the displacement field on the surfaces is considered as in Eqs. (1-a) and (1-b) [6].

$$u_j(x,z,t) = u_0^j(x,t) + z\psi_x^j(x,t) \quad (1-a)$$

$$w_j(x,z,t) = w_0^j(x,t), \quad j = t, b \quad (1-b)$$

For the beam core, the displacement field equations are in the form of Eqs. (2-a) and (2-b) [3].

$$u_c(x,z,t) = u_0(x,t) + z_c u_1(x,t) + z_c^2 u_2(x,t) + z_c^3 u_3(x,t) \quad (2-a)$$

$$w_c(x,z,t) = w_0(x,t) + z_c w_1(x,t) + z_c^2 w_2(x,t) \quad (2-b)$$

With the displacement functions defined in Eqs. (1) and (2), the strain and stress distributions are determined in each of the layers. The required dynamic equations, rotational inertia, and boundary conditions are derived from the Hamiltonian principle [7]. Boundary conditions of the Beck's beam are derived from the Hamiltonian principle; the values

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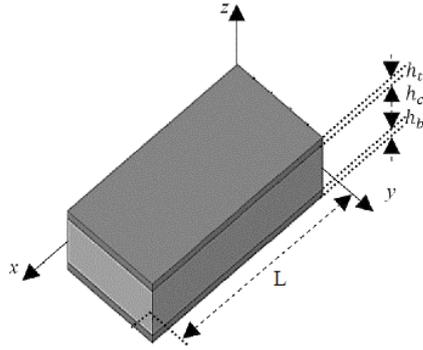


Fig. 1. Geometrical properties of Beck's sandwich beam

of the unknown displacement functions at the two boundary points of X_1 and X_2 are calculated from the value of the function at other points. After applying boundary conditions at the beginning and end-points of the network, the number of unknowns decreases to $9(N-2)$. To solve the reduced equation, eigenvalues for different values of P force are calculated and, given the values of oscillatory frequencies, the stability or instability of the beam motion is determined under the influence of the follower force. Due to the lack of access to an analytical solution for the existing differential equation system, the Generalized Differential Quadrature Method (GDM) is used [8]. In this method, the first and second-order derivatives of each uniform and differentiable function of $f(x)$ at point $x = x_i$ are approximated by Eqs. (3-a) and (3-b) using Taylor expansion [8].

$$\frac{df(x_i)}{dx} = \sum_{j=1}^N a_{ij} f(x_j) \tag{3-a}$$

$$\frac{d^2 f(x_i)}{dx^2} = \sum_{j=1}^N b_{ij} f(x_j) \tag{3-b}$$

In Eqs (3-a) and (3-b), N is the number of network grid points. As can be observed, in this method, the derivatives of the function are calculated at each point of the weighted sum of the function itself at network grid points. The length of the beam is disrupted by Eq. (4).

$$X_i = a(1 - \cos[(2i - 3)\pi / 2(N - 2)]) / 2, \tag{4}$$

$i = 2, 3, \dots, N - 1$

The set of equations of motion of the beam converts into the problem of eigenvalues of Eq. (5).

$$[K]\{X\} = \omega^2 [M]\{X\} \tag{5}$$

where the square matrices of $[M]$ and $[K]$ represent the stiffness matrix and beam mass matrix, respectively. The unknown vector of $\{X\}$ also contains the values of the displacement functions at the network grid points. To check the validity and validation process, the results of the present study are compared with the results in Ref. [9].

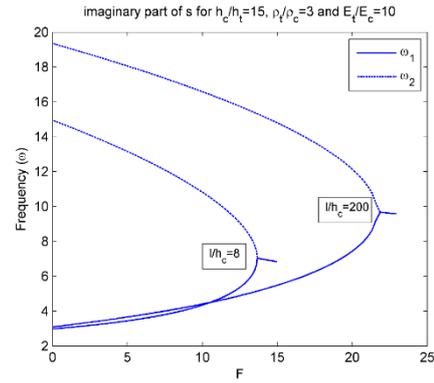


Fig. 2. Variation of the frequencies of the first and second oscillations of different values of the length to core thickness ratio.

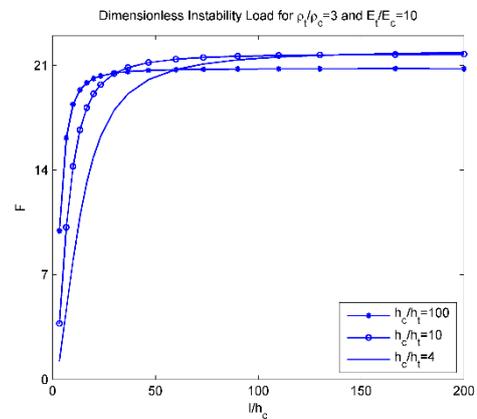


Fig. 3. Variation of the dimensionless flutter force with the length to core thickness ratio for different core thickness to shell thickness ratios.

3. RESULTS AND DISCUSSION

At times when the imaginary part of the first and second frequencies is equal, the system is at the threshold of instability and the flutter phenomenon occurs. Variations of the frequencies of the first and second oscillations of a high order sandwich beam for two different values of the length to the core thickness ratio are shown in Fig. 2. As observed, with the increment of the length to the core thickness ratio, the force and frequency of the flutter will increase. This increment in the force and frequency is due to change of beam becoming thinner and taller, in which with the increment of the value of the length to core thickness ratio, the beam will be considered taller and thinner and a large amount of the force is spent on swinging the beam.

In Fig. 3, the effect of core thickness to shell thickness ratio on the instability threshold force value of a symmetric sandwich beam is investigated. Accordingly, in the long beams, as the shell thickness increases, a larger proportion of the follower force is attributed to their oscillation, resulting in a larger instability threshold force.

4. CONCLUSION

The results of this research are presented below:

- 1- In tall beams, the threshold value of the fluttering phenomenon tends to the corresponding results in Timoshenko's beam.
- 2- When the imaginary part of the first and second frequencies becomes the same, the system is on the verge of instability and the fluttering phenomenon occurs.
- 3- In tall beams, as the thickness of the surfaces increases, the amount of instability threshold force increases.
- 4- In sandwich beams, the force and the flutter frequency increase, as the length to core thickness ratio increases

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