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Dynamic analysis of damping mechanism in welded multilayered mild steel beams

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ABSTRACT

Welded joints are often used to fabricate assembled structures in machine tools, automotive and many such industries requiring high damping. Vibration attenuation in these structures can enhance the dynamic stability significantly. A little amount of work has been reported till date on the damping capacity of welded structures. The present work outlines the basic formulation for the slip damping mechanism in multilayered and welded structures, vibrating under dynamic conditions. The numerical stability of the method and its applicability to actual working conditions have been investigated in the case of a tack welded cantilever beam structure with multiple interfaces. The developed damping model of the structure is found to be fairly in good agreement with experimental data.

1. Introduction

With the increasing use of welded, bolted and riveted layered beams as structural members there has been a critical need for development of reliable and practical mathematical models to predict the dynamic behavior of such built-up structures. Joints are inherently present in almost all assembled structures which contribute significantly to the slip damping. Joints have a great potential to reduce the vibration levels thereby attracting the interest of many researchers. In an earlier attempt, theory of structural damping in a built-up beam has been investigated by Pian and Hallowell [24] considering the beam being fabricated in two parts and connected by riveted cover plates. Goodman and Klumpp [9] examined the energy dissipation by slip at the interfaces of a laminated beam. In fact, investigators such as Cockerham and Symmons [3], Hess et al. [12] and Guyan et al. [10] considered various friction and excitation models, while Barnett et al. [1] and Maugin et al. [15] considered interfacial slip waves between two surfaces for the measurement of damping capacity of these structures.

Studies by researchers such as Goodman [8], Earles [6], Murty [17] have shown that the energy dissipation at the joints occurs due to frictional energy loss at the interfaces which is more than the energy loss at the support. In fact following the work of Goodman and Klumpp [9], early workers, such as Masuko et al. [14], Nishiwaki et al. [22], and Motosh [16] studied the damping capacity of layered and bolted structures assuming uniform intensity of pressure distribution at the interfaces. However, their work is limited to the static analysis of layered and jointed structures with single interface.

Hansen and Spies [11] investigated the structural damping in laminated beams due to interfacial slip. They analyzed a two layered plate model with an assumption that there exists an adhesive layer of negligible thickness and mass between the two layers such that some amount of micro-slip originates at the frictional interfaces which contributes to the slip damping. They have also shown that the restoring force is developed by this adhesive medium and is proportional to the interfacial micro-slip.

Nanda and Behera [19] examined the interfacial slip damping in multilayered bolted structures and developed a theoretical expression for the pressure distribution at the interfaces of a bolted joint by curve fitting the earlier data reported by Ziada and Abd [27]. They developed an eighth order polynomial for the interface pressure in terms of the normalized radial distance from the center of the bolt such that the function assumes its maximum value at the center of the bolt and decreases monotonically and radially away from the center. They further extended their work by developing a generalized mathematical expression for the logarithmic damping decrement of such structures with multiple interfaces. Nanda and Behera [20,21] and Nanda [18] further studied the distribution pattern of the interface pressure as well as the damping capacity of layered and jointed structures. Moreover, they established the effects of number of layers, diameter of bolts and use of washers

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on the damping capacity of bolted structures by carrying out both numerical analysis and experiments. However, they neglected the effect of in-plane bending stresses on the dynamic slip and damping capacity. Moreover, their work is limited to the static analysis of layered and bolted structures.

Recently, Damisa et al. [4] examined the effect of linear interface pressure distribution on the mechanism of slip damping for layered beams vibrating at static conditions. However, Olunloyo et al. [23] in their analysis on slip damping of clamped beams included other forms of interfacial pressure distributions such as polynomial or hyperbolic expressions. Damisa et al. [5] examined the effect of non-uniform interface pressure distribution on the mechanism of slip damping for layered and clamped beams under dynamic loads. Though these researchers considered the in-plane distribution of bending stresses but all the analysis is limited to the structures with single interface. They did not consider the effect of multiple interfaces on the damping capacity of these structures.

The aim of the present work is to develop a mathematical model to estimate the damping capacity of welded structures with multiple interfaces. The problem is idealized as a multilayered and tack welded beam model, vibrating at dynamic conditions. The beam is cantilevered from one end. Experiments are performed on mild steel specimens with a number of layers under different initial conditions of excitation to validate the theory developed. It is observed that a considerable increase in damping capacity can be achieved by increasing the number of layers. A uniform and coherent treatment of the subject is presented, by integrating theoretical and experimental techniques.

2. Theoretical analysis

2.1. Static analysis

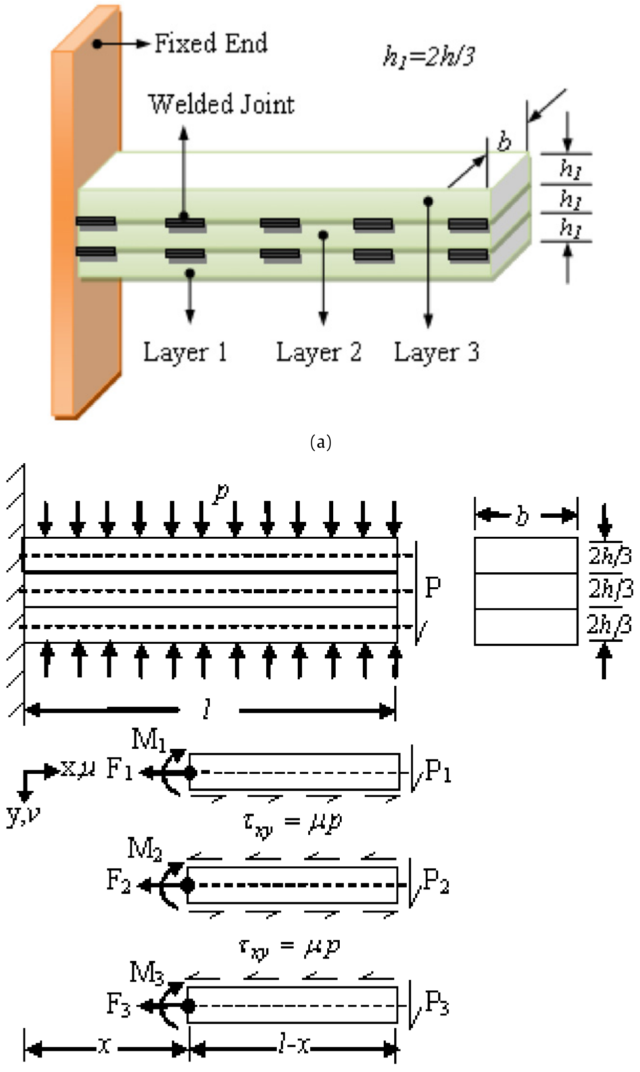
To study the mechanism of slip damping in multilayered built-up structures with multiple interfaces, the tack welded cantilever beam model as shown in Fig. 1(a) is considered with overall thickness $2h$, width b, length l and made up of 'm' number of laminates of equal thickness $(2h/m)$, so that the slip is occurring on $(m-1)$ number of interfaces simultaneously. The loading consists of uniformly distributed pressure at the interfaces due to contact between flat bodies, and a concentrated load P applied at the free end, $x = l$. The continuity of stress and vertical displacement 'v' is imposed at the interfaces. Each of the laminates of thickness $2h/m$ is considered separately with the loading as depicted in Fig. 1(b). At some finite value of P, the shear stress at the interfaces will reach the critical value for slip $\tau_{xy} = \mu p$ where μ and p are the kinematic coefficient of friction and interface pressure, respectively. Additional static force due to excitation will produce a relative displacement $\Delta u(x)$ at the interfaces.

2.1.1. Interface pressure distribution

The contact pressure for flat surfaces with rounded corners has been found out by Ciavarella et al. [2], which shows a non-uniform distribution pattern at the interfaces. Contrary to this, the pressure distribution at the interfaces is assumed to be uniform owing to the contact of the upper layer over the lower one. In the present analysis, the welded beams are perfectly flat and the relation for uniform pressure distribution as given by Johnson [13] and Giannakopoulos et al. [7] due to contact of two flat bodies has been considered and the same is given by

$$p(x) = \frac{P}{b} \tag{1}$$

where P and b are the normal load per unit length and width of the beam, respectively.



(a)

(b)

Fig. 1. (a) Three layered tack welded cantilever beam model. (b) Three layers of the jointed beam depicting load and co-ordinates.

2.1.2. Analysis of static response

The resultant bending moment about the centroid of each laminate as shown in Fig. 1(b) is found to be:

$$M_m = \frac{1}{m}\left[P - \frac{2(m-1)\mu pbh}{m}\right](l-x) \tag{2}$$

Invoking the relation between bending moment and curvature as derived by Warburton in [26], we get:

$$M = -EI\frac{\mathrm{d}^2 v}{\mathrm{d}x^2} \tag{3}$$

where E is the modulus of elasticity.

Putting expression (3) in (2) the following expression is obtained:

$$\frac{\mathrm{d}^2 v}{\mathrm{d}x^2} = \frac{1}{mEI}\left[P - \frac{2(m-1)\mu pbh}{m}\right](l-x) \tag{4}$$

where $I = b(\frac{2h}{m})^3/12$ is the moment of inertia of the cross-section of the beam.

Integrating expression (4) once we get:

$$\frac{\mathrm{d}v}{\mathrm{d}x} = \frac{3m^2}{2Ebh^3}\left[P - \frac{2(m-1)\mu pbh}{m}\right]\left(lx - \frac{x^2}{2}\right) + C_1 \tag{5}$$