Sandwich Treatment In FRP Beams: Static And Dynamic Response

Y. Swathi[1]* and Sd. Abdul Kalam[2]
[1]*Graduate Student, Mechanical Engineering Department, PVP Siddhartha Institute of Technology, Vijayawada, India*
[2]*Asst. Professor, Mechanical Engineering Department, PVP Siddhartha Institute of Technology, Vijayawada, India*

Abstract

The present investigation deals with the static and dynamic analysis of a sandwich beam, consisting of a viscoelastic core layer and 2-face layers, each with 4 FRP layers, subjected to a) simply supported and b) clamped-clamped boundary conditions. The problem is analyzed using 3-dimensional Finite Element Method and is modelled in ANSYS software. Static and dynamic response of the beam is studied by varying the parameters of the core layer such as its geometry and damping coefficient. It is observed that the thickness of the core layer influences both static and dynamic response, and the damping coefficient is useful to control the dynamic response of the beam. This type of analysis is useful in selecting the materials and their arrangement for the safe design of sandwich structures in view of strength, stiffness and sufficient damping to control the harmonic response.

1. Introduction

Selection of materials in designing the structural and/or mechanical components play an important role and is fixed based on the strength, stiffness, cost and other mechanical properties such as hardness, toughness, wear resistance etc.. Materials selected in view of the above requirements may not have internal damping capacity. When the structures are subjected to harmonic loads of high frequencies, conventional damping techniques such as providing external dashpots, arranging dynamic vibration absorbers may not have control on the dynamic response of the structures resulting in failure at resonance frequencies.

Arrangement of soft-core material that requires more energy to deform provides internal damping of structures known as sandwich treatment. Sandwich treatment will reduce the amplitude of oscillation depending upon the location, volume and Mechanical properties of the core layer in the structure. It is also important to study the effect of sandwich treatment on static response of the structure in order to confirm the safe design.

When a sandwich structures with thin soft cores (STSC) is transversely loaded, the two faces tend to act as two independent beams, bending along their centroids, rather than along the neutral axis of the beam as a whole [1]. Under these conditions, the core is subjected to high shear deformation levels, and its damping capacities are misused. Unfortunately, when the facings tend to deflect independently with each other, the sandwich effect is partially lost, and the flexural stiffness decays, adversely affecting also the ability of the structure to avoid buckling phenomena. Therefore, the optimization of STSCs deserves careful examination, requiring reliable analytical methods to measure their mechanical behavior. It has long been recognized that classical lamination theory (CLT), although effective in modelling the in-plane and bending response of thin laminates, is unable to describe accurately the through-the-thickness shear stresses and strains occurring in thick laminates and sandwich structures, largely overestimating the flexural stiffness, especially when STSCs are concerned. To take into account the shear effects, yet preserving the single-layer plate simplicity allowed by CLT, some researchers [2–4] have developed first-order shear deformation theories (FSDT), resulting in shear correction factors to be applied when the shear rigidities are evaluated. Physically speaking, the hypothesis of the cross section remaining orthogonal to its mid-plane is removed, and the actual shear strain field is substituted by an equivalent 'mean' value. More recently, higher order shear deformation theories (HSDT), taking into account the layer wise nature of the material and involving higher order terms in Taylor's expansions of the displacements along the thickness, have been also developed. Frostig et al. [5], in treating sandwich beams, ideally subdivided the sandwich into two substructures, one representing the shear absorption capability of the core, and the other free of shear stresses. A more refined analysis was carried out by Kant and Swaminathan [6], who expanded the in-plane displacements as cubic functions of the thickness coordinate, assuming an incompressible core; the equation of equilibrium were obtained using the principle of minimum potential energy; closed-form solutions for particular cases were developed by solving the boundary value problem through the Navier's technique. The hypothesis of core incompressibility was removed, for instance, in the solution proposed by Pandit and co-workers [7], assumed a transverse displacement varying quadratically within the core, and employed a computationally efficient C0 finite element to solve the problem. In almost all the works published, the models proposed have been validated numerically, comparing their results with exact formulations available in the literature for special laminates [8,9], whereas little experimental data have been generated on the subject.

Malekzadeh et al. [10] determined the damped natural frequencies, loss factors, and local and global mode shapes of plates. Iaccarino et al. [11] studied the role played by the shear rigidity on the elastic behaviour of an STSC by carrying out flexure tests in three-point bending on thick unidirectional carbon-fiber-reinforced plastics (CFRP) with a thin soft core, varying the beam span.

From the review of the literature on the analysis of STSC structures, the authors of the present paper are inspired to study the core layer parameters such as its thickness and damping coefficient on static and dynamic response of a 3-layered sandwich beam with composite face layers. The intension in the study is to isolate the effect of the set parameters so that the outcome of the work will be useful in predicting the reasons for the behaviour of a sandwich structure made of complex materials such as FRPs where so many parameters such as layer sequence, layer orthotropy, layer anisotropy influence the response of the structure in addition to core layer parameters.

2 PROBLEM MODELING

A Three layered sandwich beam of 1m length, 0.05m wide and 0.1m height is modeled in ANSYS software using 8node brick element SOLID185 [12]. The thickness of the core layer is varied as per t2/h ratio (0.10, 0.2 and 0.30). Where t2 is core layer thickness and h is the total height of the beam. The core layer is located at the mid height of the beam.

a) Simply supported boundary conditions and
b) Clamped-clamped boundary conditions

are implied at the ends of the beam and a line load of 1000N is applied at the top center of the beam for static and harmonic analysis (Fig.1).

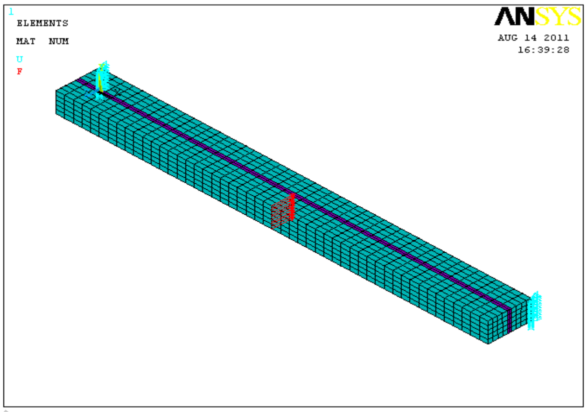

Fig. 1: a) FE model of simply supported Sandwich Beam with continuous core viscoelastic layer (TYPE-1)

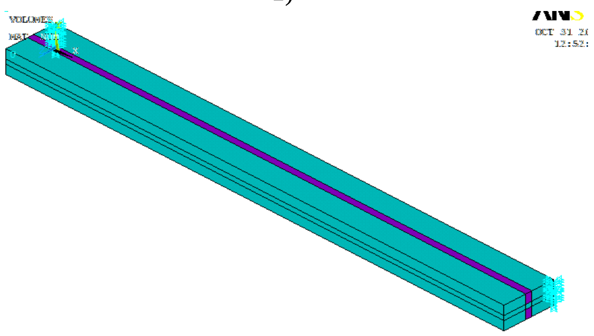

Fig. 1: b) Geometric model of simply supported Sandwich Beam with discontinuous core viscoelastic layer, beam having material continuity of face layers (TYPE-2)

3 ANALYSIS OF RESULTS

The finite element mesh is refined until the results are satisfactory and then static, modal and harmonic analyses are performed on sandwich beam of both type-1 and type-2 beams. Fig. 2 shows the static deformation of the beam. Variation of static deflection with respect to t2/h is plotted in Figs. 3-6 for both the boundary condition cases. It

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is observed that there is a decrease of the deflection with respect to t2/h. which is due to the increase in stiffness of the structure because of the composite face layers.

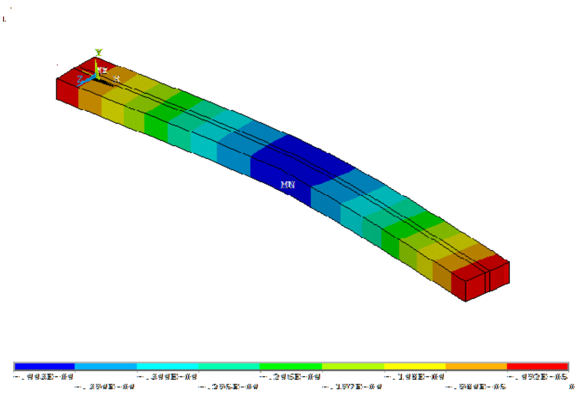

Fig 2: Static deflection of sandwich beam of type-1 beam with clamped-clamped boundary conditions

- **For Simply supported boundary conditions**

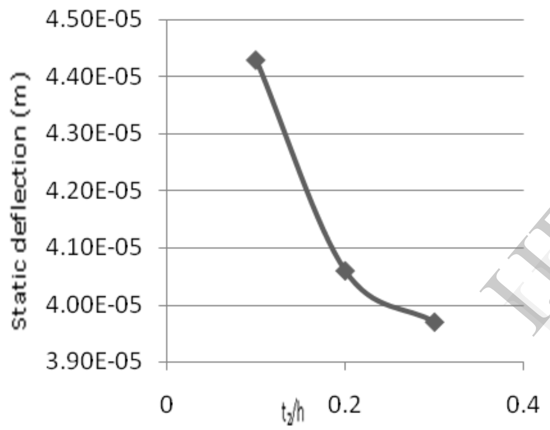

Fig 3. Static deflection vs. t2/h for simply supported Type-1 beam

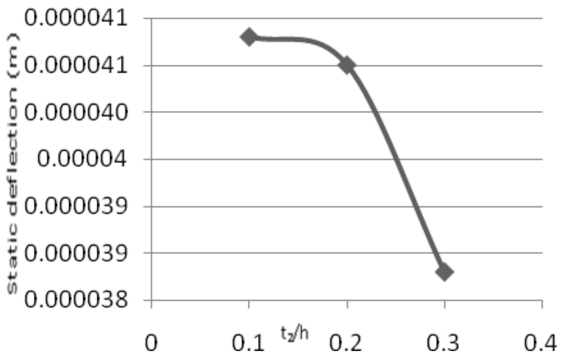

Fig 4: Static deflection vs. t2/h for simply supported Type-2 beam

- **For clamped-clamped boundary conditions**

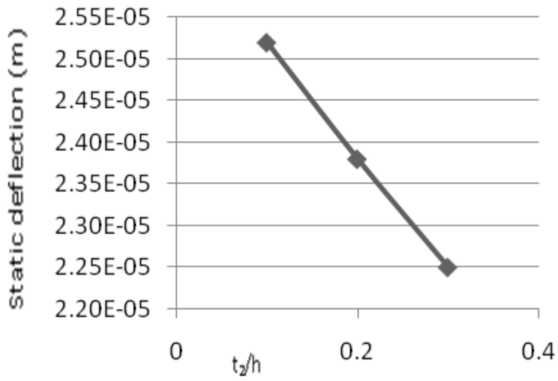

Fig 5: Static deflection vs. t2/h for clamped-clamped type-1 beam

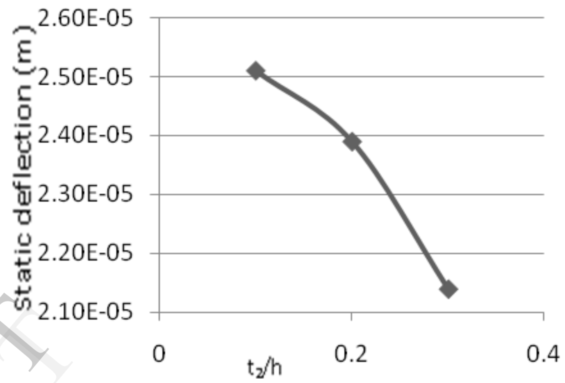

Fig 6: Static deflection vs. t2/h for clamped-clamped type-2 beam

Natural frequencies of the sandwich beam for the first five modes are obtained and data is provided in tables 1-4 against various values of t2/h. there is an increase in frequency with mode number and decreasing trend with respect to t2/h is observed. Increase in t2 causes for the reduction in stiffness of the structure resulting in decreasing the natural frequencies. First five mode shapes of the beam for t2/h=0.1 are shown in Figs. 4-8.

- **For Simply supported boundary conditions**

t2/h	mode1	mode2	mode3	mode4	mode5
0.1	203.44	392.85	523.23	598.12	978.86
0.2	196.7	403.81	507.25	574.39	943.54
0.3	193.56	398.12	523.53	574.91	939.22

Table 1: First five mode frequencies for simply supported type-1 beam

t2/h	mode1	mode2	mode3	mode4	mode5
0.1	199.72	410.82	493.96	574.24	949.75
0.2	196.92	403.09	518.35	577.61	943.99
0.3	193.47	402.24	534.55	576.47	948.13

Table 2: First five mode frequencies for simply supported type-2 beam

- **For clamped-clamped boundary conditions**

t2/h	mode1	mode2	mode3	mode4	mode5
0.1	351.24	577.45	766.91	916.08	1312.8
0.2	348.93	582.81	835.19	917.66	1356.1
0.3	346.25	588.12	916.46	918.18	1399.8

Table 3: First five mode frequencies for clamped-clamped type-1 beam

t2/h	mode1	mode2	mode3	mode4	mode5
0.1	349.61	579.72	780.08	908.56	1322.4
0.2	346.65	584.85	868.9	907.43	1373.7
0.3	343.75	597.23	904.98	956.51	1435.6

Table 4: First five mode frequencies for clamped-clamped type-2 beam

Mode Shapes:

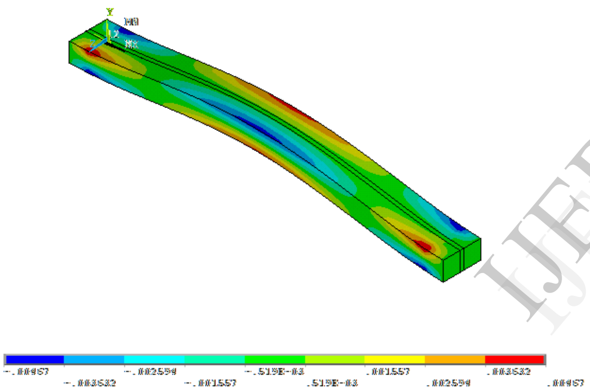

Fig. 4 First mode shape of sandwich beam

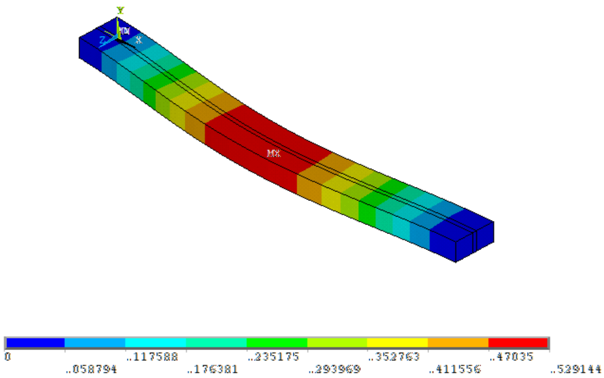

Fig. 5 Second mode shape of sandwich beam

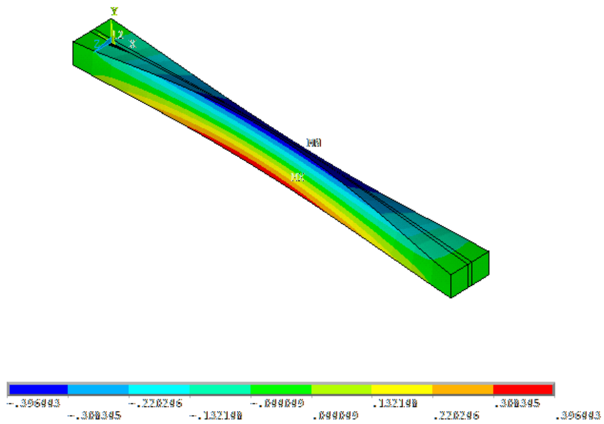

Fig. 6 Third mode shape of sandwich beam

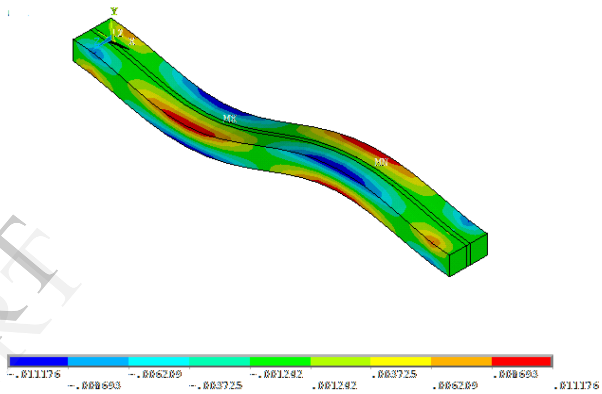

Fig. 7 Fourth mode shape of sandwich beam

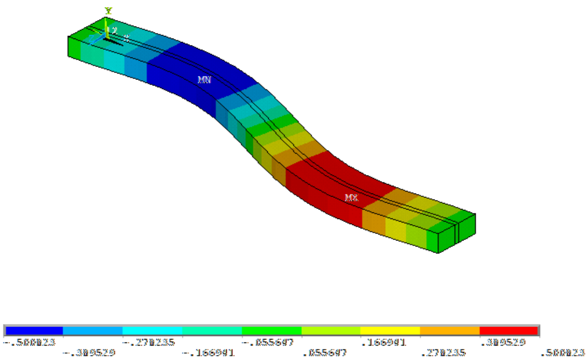

Fig. 8 Fifth mode shape of sandwich beam

Figs.9-12 shows the variation of the amplitude of midpoint of the beam at first resonance frequency for various damping coefficients and t2/h values. It is observed that the amplitude decreases with t2/h for smaller values of damping. As the damping value increases; there is a drop in amplitude. When the value of damping is very small the damping is negligible and the response is similar to the static response. As the value of damping increases, the damping effect increases which reduces the harmonic amplitude.

- **For Simply supported boundary conditions**

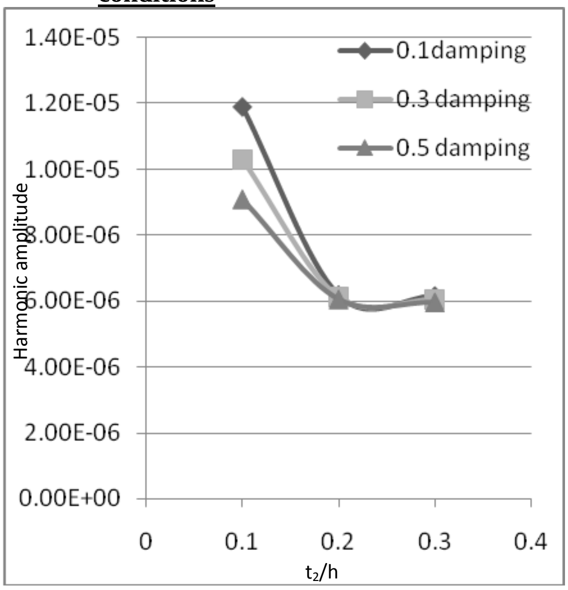

Fig. 9 Harmonic amplitude vs. t2/h and for various damping values of core for simply supported Type-1 beam.

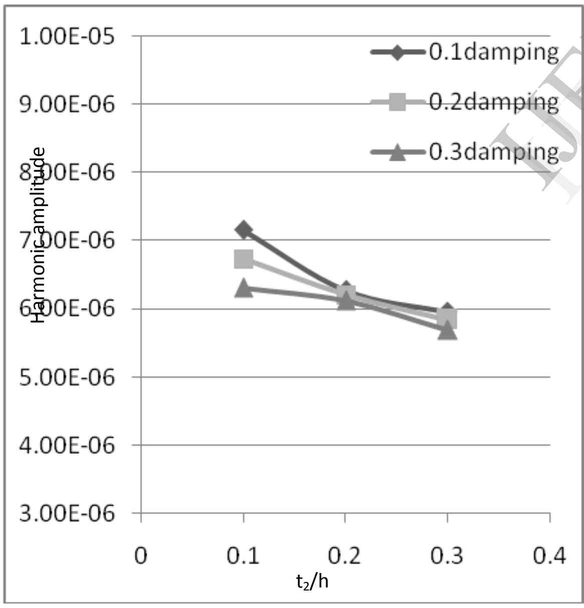

Fig. 10 Harmonic amplitude vs. t2/h for various damping values of core for simply supported type-2 beam

- **For clamped-clamped boundary conditions**

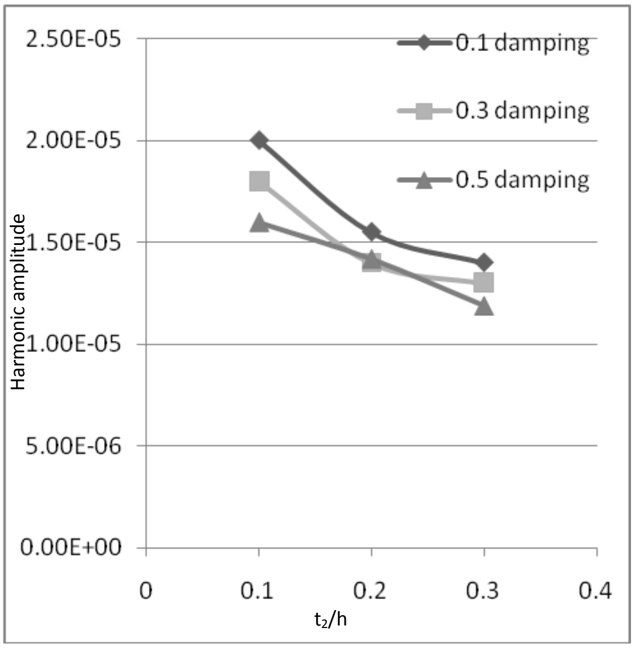

Fig. 11 Harmonic amplitude vs. t2/h and for various damping values of core for clamped-clamped type-1 beam

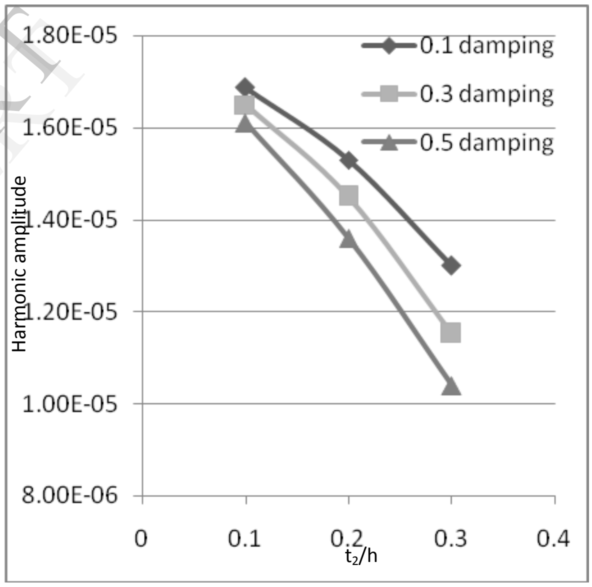

Fig. 12 Harmonic amplitude vs. t2/h for various damping values of core for clamped-clamped type-2 beam

- **For Simply supported boundary conditions**

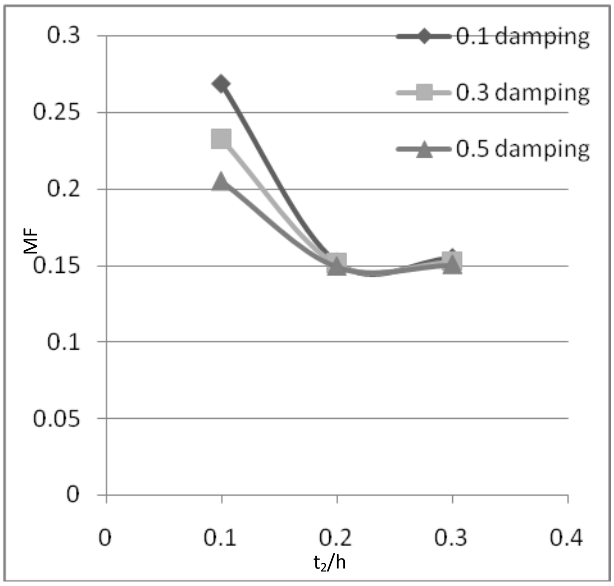

Fig. 13 Magnification factor vs. t2/h and for various damping values of core for simply supported type-1 beam

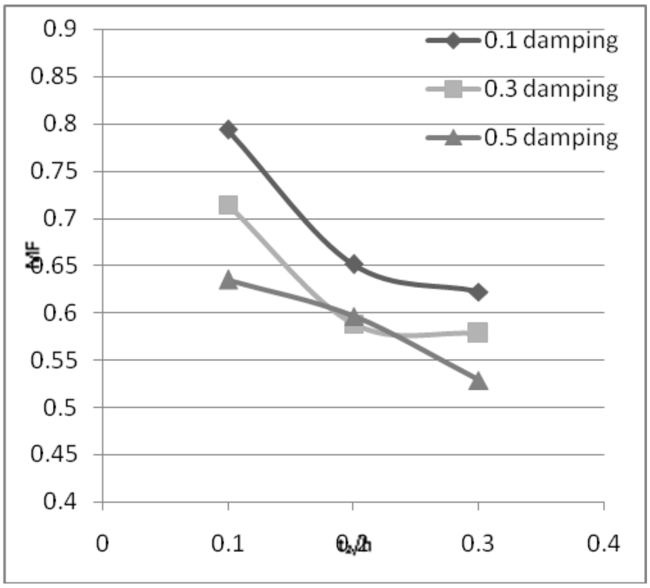

Fig. 15 Magnification factor vs. t2/h and for various damping values of core for clamped-clamped type-1 beam

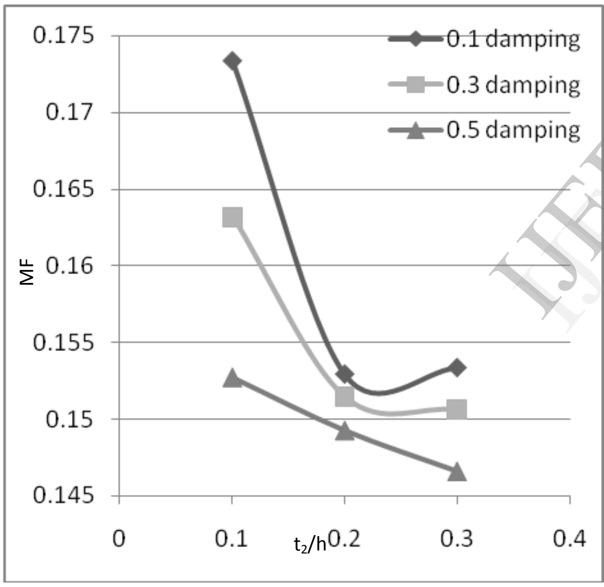

Fig. 14 Magnification factor vs. t2/h for various damping values of core for simply supported type-2 beam

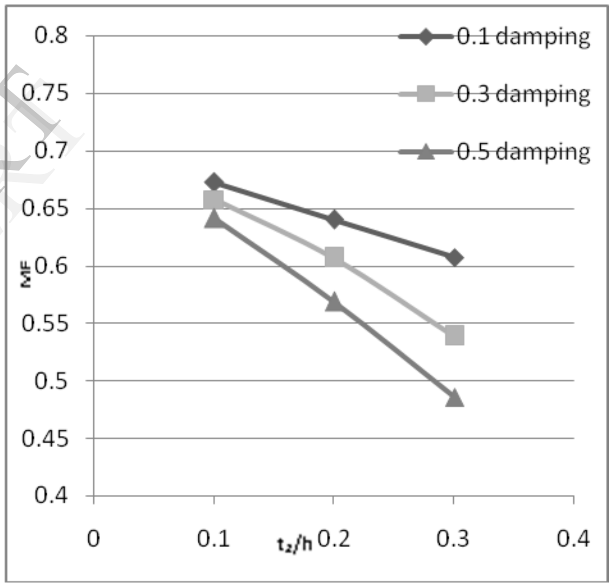

Fig. 16 Magnification factor vs. t2/h for various damping values of core for clamped-clamped type-2 beam

- **<u>For clamped-clamped boundary conditions</u>**

Fig. 13-16 shows the variation of the magnification factor (amplitude/deflection) with respect to t2/h. from this diagram one can realise that any value of damping contributes in absorbing the vibratory energy, there by reducing the dynamic deflection than the static deflection.

CONCLUSIONS

A three dimensional Finite Element Analysis is performed to study the static and dynamic response of a sandwich beam with a viscoelastic layer as core material in the present study. It is realized that selecting the core material with high damping coefficient gives better performance in both the load cases rather than increasing the thickness of the core layer.

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