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# Free Vibration Response of Laminated Composite Plate Shear Walls

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**ABSTRACT:-** Laminated composite plates have been widely used in modern engineering applications due to their high strength to weight, stiffness to weight ratios and modulus. In this paper, the effect of infill laminated composite plates, thickness of plate and number of stories on the free vibration response of laminated composite plate shear walls are examined with respect to natural frequencies and mode shapes. Comparative study is conducted to investigate the effect of infill laminated composite plates, thickness of plate and number of stories on the free vibration response of laminated composite plate shear walls with compared to the performance of steel plate shear walls using the finite element system ANSYS16.

**Keywords:-** Shear wall, laminated, composite plate, steel plate, modal analysis.

## I. INTRODUCTION

Steel plate shear walls have been extensively used as lateral load resisting systems in the past few decades. The most important characteristic of steel plate shear walls is its ability to dissipate high energy and it provide ductility in cases of extreme load events. The overall structures of steel plate shear walls consists of steel infill plate surrounded by boundary beams and columns and it can be constructed in two types which are unstiffened and stiffened infill steel plates. A steel plate shear wall system can be idealized as a cantilevered vertical plate girder, in which the steel infill plates act as the web, the boundary columns represents the flanges and the boundary beams act as the transverse stiffeners. Laminated composite plates due to their merits such as low density, high stiffness and high strengths are alternative system that is used as infill plate in shear walls. The term laminated refers to a composite structural material that is formed by combining two or more materials that are bonded together by strong adhesives. The laminated composite plates are created by constructing plates of two or more thin bonded layers of materials and it can be either cross-ply laminates or angle-ply laminates [1].

Investigation of steel plate shear walls with and without stiffener have been carried out by many researchers. However, studies on using the laminated composite plates as infill plate in shear walls are limited. R. Esfandiar and M. A. Barkhordari, [2] developed a nonlinear finite element models for one and four stories thin unstiffened steel plate shear walls. The effect of variations of stiffness of plate and frame, interaction between frame and plate and reactions in plate edge connection were investigated. M. Lashgari, [3] presented the finite element analysis of low yield point steel shear walls and a series of nonlinear cyclic analyses were carried out to obtain the stiffness, strength, deformation capacity, and energy dissipation capacity of the low yield point steel shear walls. The effect of width to thickness ratio of steel plate on buckling behaviour, and energy dissipation capacities was investigated. M. Guendel et al. [4] investigated experimentally and numerically using steel plate shear walls as seismic retrofit for existing reinforced concrete structures. Five full scale cyclic tests on a pure reinforced concrete frame, on pure steel plate shear walls with different shear panels and on reinforced concrete frames retrofitted by steel plate shear walls were carried out. M. K. Poul and F. N. Alahi, [5] studied numerically nonlinear behaviour of strengthened steel plate shear walls by means of glass fiber reinforced polymer laminates. Simulation of one story unstiffened steel plate shear wall was considered using the finite element method. Nonlinear large displacement analysis of model was carried out using the finite element method and effects of GFRP laminates on the seismic behaviour of strengthened steel plate shear walls were investigated. M. K. Poul and F. N. Alahi, [6] investigated theoretically and numerically nonlinear behavior of strengthened steel plate shear walls by FRP laminates. The composite plate frame interaction method had been introduced to predict the shear behaviour of the composite steel plate shear wall systems. Several models of one story unstiffened and strengthened steel plate shear walls subjected to quasi-static cyclic loading were simulated by the finite element method and the results were presented. F. N. Alahi and M. K. Poul [7] investigated experimentally the nonlinear behaviour of strengthened steel plate shear walls by the GFRP laminated layers. Experimental models were scaled as a one story steel shear panels with hinge type connections of the boundaries at four corners. Tests were designed to evaluate the effect of the GFRP layers, the number of GFRP layers and the orientation of GFRP layers on the stiffness of composite steel plate shear walls. G. K. Verma and S. Maru, [8] presented a detailed summary of research works that were performed on steel plate shear walls to evaluate the static and dynamic behaviour of steel plate shear walls for the past three decades. The review might be useful for researchers and engineers in order to formulate efficient seismic design, analysis techniques and design methods for steel plate shear walls subjected to dynamic loading. M. Ghaderi et al. [9] modelled stiffened steel shear walls using the finite element method to investigate the effect of stiffeners arrangement on strength, stiffness and ductility of steel plate shear walls. Nonlinear static analysis was done on samples and the results were compared with experimental models. I. Hadzhiyaneva and B. Belev, [10] presented experimental and numerical evaluation of a scaled partially composite single story steel plate shear wall under cyclic loading. The slender steel web panel had a single sided reinforced concrete encasement that it was attached with headed shear studs in order to prevent the shear buckling and tension field action of the slender web when it is subjected to lateral seismic forces. The resistance, ductility and energy dissipation capacity of composite steel plate shear wall were investigated and compared its performance with the bare steel counterparts. A. Sunny and P.E. Kavitha, [11] studied the effect of variation in cutout size and cutout shape on the behaviour of steel plate shear walls by the finite element method. The time history analysis was done and the effects of variation in cutout size and cutout shape in infill steel plate on displacement and stress distribution in steel plate shear walls were investigated. Therefore, the aim of this paper is to investigate the free vibration response of laminated composite plate shear walls and compared it with the performance of steel plate shear walls using the finite element system ANSYS16. Laminated composite plates are considered with symmetric cross-ply laminates arrangements and the modal analysis is carried out for steel and laminated composite plates shear walls.

## II. MODAL ANALYSIS

The modal analysis is used to determine the vibration characteristics of a structure which it are natural frequencies and mode shapes while it is being designed. It also can be a starting point for another dynamic analysis such as a transient dynamic analysis, a harmonic response analysis, or a spectrum analysis. The dynamic behaviour of the structure is defined by a special frequency spectrum which consisting of an infinite number of natural frequencies and mode shapes which can be found by knowing the geometrical shape, mass distribution, stiffness and boundary conditions of the structures. In general, the equation of motion for a linear dynamic system is [12]:

$$[\boldsymbol{M}]\{\ddot{\boldsymbol{u}}\} + [\boldsymbol{C}]\{\dot{\boldsymbol{u}}\} + [\boldsymbol{K}]\{\boldsymbol{u}\} = \{\boldsymbol{F}(\boldsymbol{t})\} \quad (1)$$

Where:

**[M]** = mass matrix, [**C**] = damping matrix, [**K**] = stiffness matrix, {**F**(**t**)} = time varying load vector, $\{\ddot{\boldsymbol{u}}\}$ = nodal acceleration vector, $\{\dot{\boldsymbol{u}}\}$ = nodal velocity vector and $\{\boldsymbol{u}\}$ = nodal displacement vector.

For free vibration the equation (1) becomes:

$$[\boldsymbol{M}]\{\ddot{\boldsymbol{u}}\} + [\boldsymbol{C}]\{\dot{\boldsymbol{u}}\} + [\boldsymbol{K}]\{\boldsymbol{u}\} = \boldsymbol{0} \quad (2)$$

When undamped linear structures are initially displaced into a certain shape, they will oscillate indefinitely with the same mode shape but varying amplitudes. The oscillation shapes are called the mode shapes and the corresponding frequencies are called natural frequencies. For undamped linear structures, the equation (2) reduces to:

$$[\boldsymbol{M}]\{\ddot{\boldsymbol{u}}\} + [\boldsymbol{K}]\{\boldsymbol{u}\} = \boldsymbol{0} \quad (3)$$

With no externally applied loads, the structure is assumed to vibrate freely in a harmonic form which is defined by:

$$\boldsymbol{U}(\boldsymbol{t}) = \boldsymbol{\varphi}\, \boldsymbol{sin}(\boldsymbol{wt} + \boldsymbol{\theta}) \quad (4)$$

which leads to the eigenvalue problem as:

$$\left[[\boldsymbol{K}] - \boldsymbol{w}^2[\boldsymbol{M}]\right]\{\boldsymbol{\varphi}\} = \boldsymbol{0} \quad (5)$$

Where **w** is the natural frequency and $\boldsymbol{\varphi}$ is the corresponding mode shape of the structure.

## III. NUMERICAL EXAMPLE

To investigate the free vibration response of laminated composite plate shear walls, the modal analysis of steel and laminated composite plate shear walls is considered. Three, five and ten stories shear walls are considered to show the effect of number of stories on the free vibration response of laminated composite plate shear walls as shown in Fig. 1. and the width and the high of story are 3.0 m. In this study, three different thickness of steel and laminated composite plates are considered which are 5 mm, 8 mm and 10 mm to show the effect of thickness on the free vibration response of laminated composite plate shear walls. For steel and laminated composite plate shear walls, all columns and beams are steel I-beam section with dimensions as shown in Fig. 2.

Laminates are composite plates consisting of four orthotropic plies of the same material and equal thickness with the overall thickness kept constant and symmetric cross-ply laminates arrangements are considered. A Epoxy/ Carbon composite material (UD 395 Gpa Prepreg) from ANSYS16 composite materials library is used for infill laminated composite plates and the materials properties are given as $E_1$ = 209 GPa, $E_2$ = 9.45 GPa, $E_3$ = 9.45 GPa, $G_{12}$ = 5.5 GPa, $G_{13}$= 5.0 GPa, $G_{23}$ = 3.9 GPa, $\nu_{12}$= 0.27, $\nu_{13}$= 0.27 , $\nu_{23}$= 0.4 and $\rho$ = 1540 kg/m$^3$ for Young's modulus, shear modulus, Poisson's ratio and density respectively. The materials properties of columns, beams and infill steel plates are given as E = 200 GPa, $\nu$= 0.3 and $\rho$ = 7850 kg/m$^3$ for Young's modulus, Poisson's ratio and density respectively.

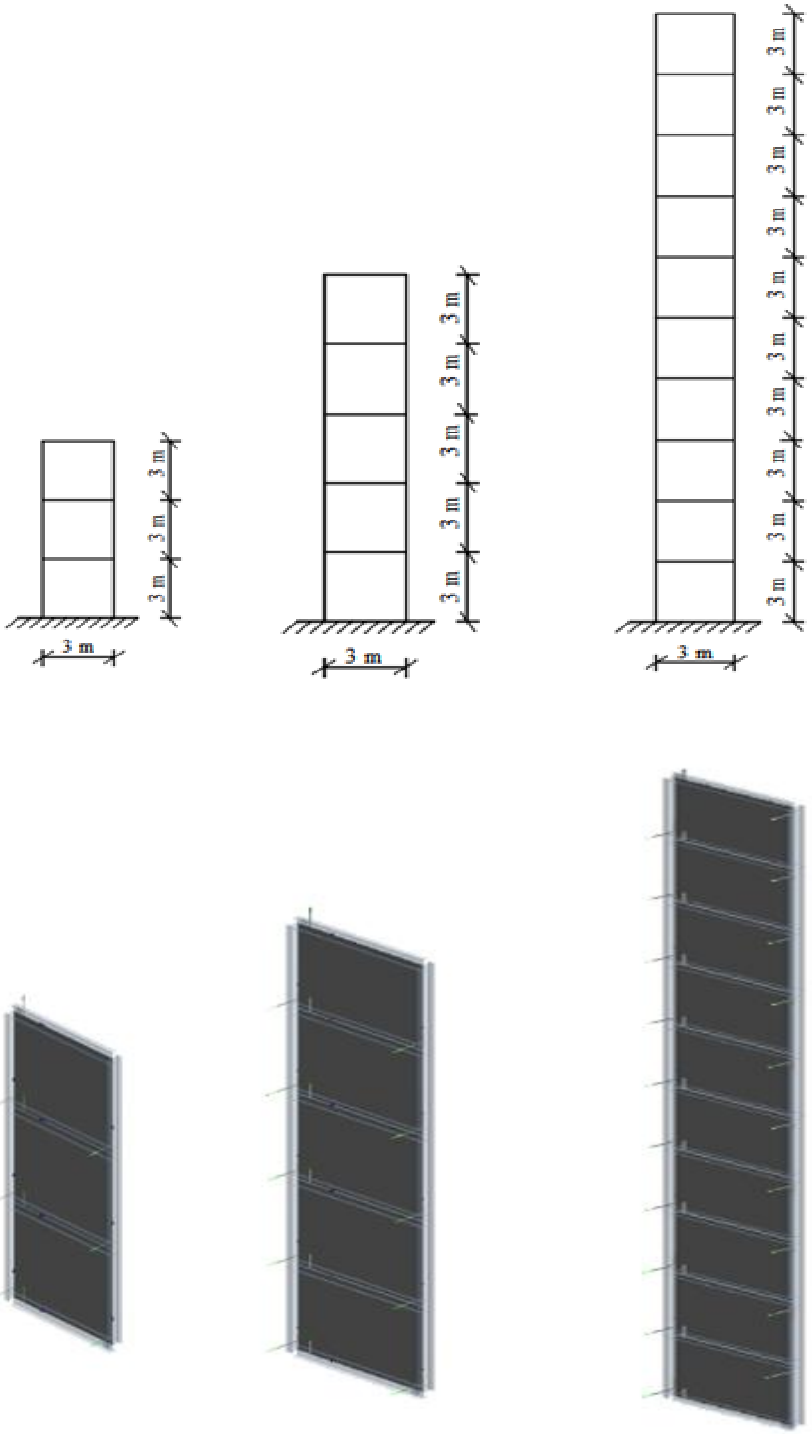



**Fig. 1:** Three, five and ten stories shear walls

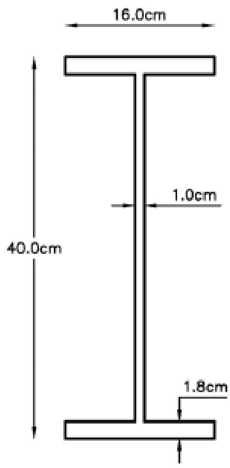
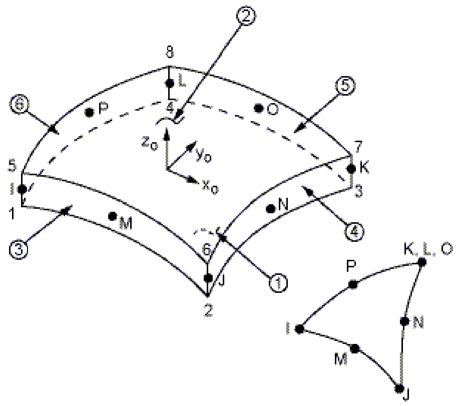



**Fig. 2:** Steel I-beam section dimensions

**3-1 Method of analysis**

The modal analysis has been done by 8-node SHELL281 element in finite element system ANSYS16. The SHELL281 as shown in Fig. 3. is a eight-node element with six degrees of freedom at each node that are translations in the x, y, and z axes, and rotations about the x, y, and z-axes. The element is suitable for analyzing thin to moderately- thick shell structures and it is appropriate for linear, large rotation and/ or large strain nonlinear applications. SHELL281 may be used for layered applications for modelling laminated composite shells or sandwich construction and the accuracy in modelling composite shells is governed by the first order shear deformation theory.



**$x_o$** = Element x-axis if element orientation is not provided.
**x** = Element x-axis if element orientation is provided.
**Fig. 3:** 8-node SHELL281 element

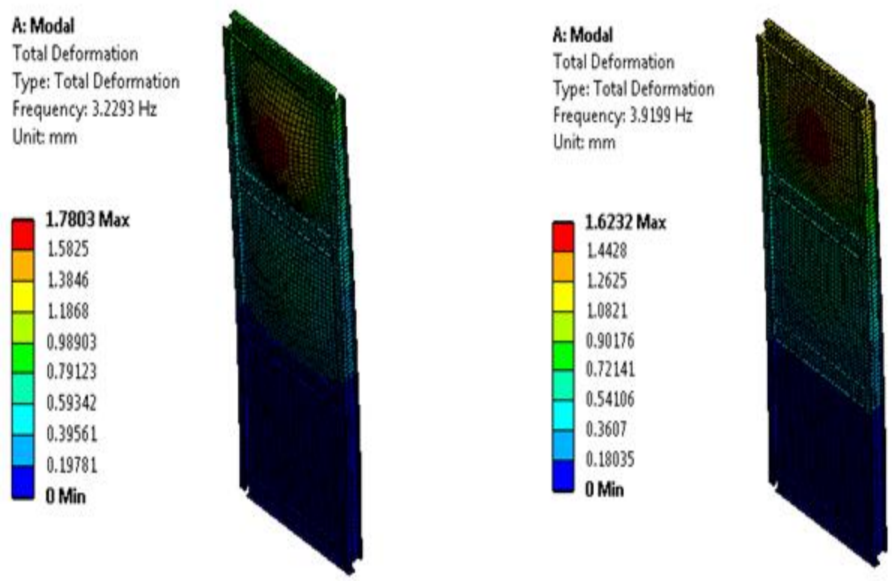
## IV. RESULTS AND DISCUSSION

The modal analysis has been carried out and the ten natural frequencies values and mode shapes for steel and laminated composite plate shear walls are obtained. To investigate the free vibration response of laminated composite plate shear walls, the results obtained are analyzed. For simplicity, the results are presented by charts as follows:

**4-1 Effects of laminated composite plates**

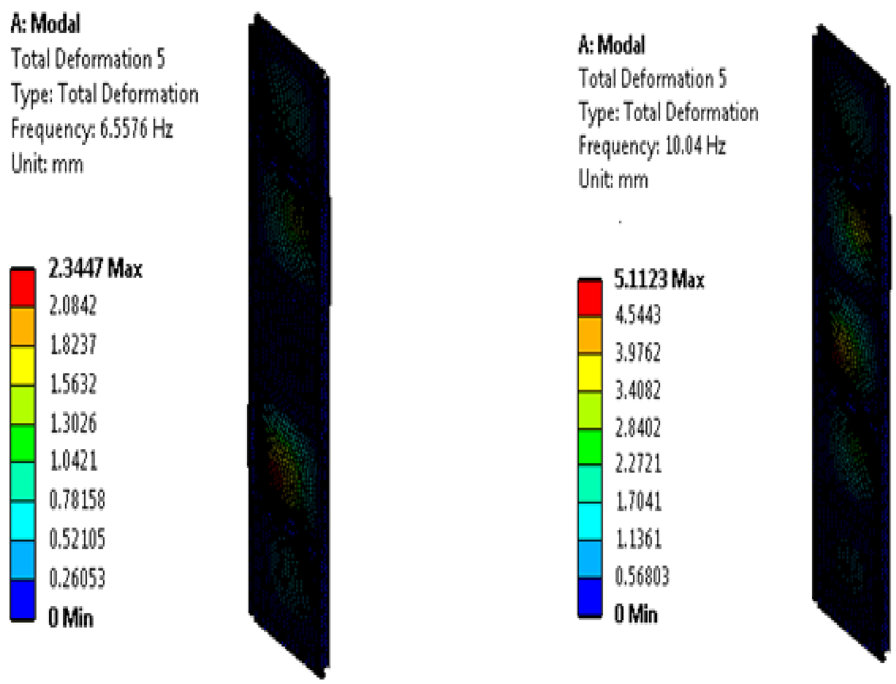
Fig. 4. presents the mode shape 1 for three stories steel and laminated composite plates shear walls with thickness of plates = 5 mm. Fig. 5. presents the mode shape 5 for five stories steel and laminated composite plates shear walls with thickness of plates = 8 mm. Fig. 6. presents the mode shape 10 for ten stories steel and laminated composite plates shear walls with thickness of plates = 10 mm. Fig. 7. presents the effect of steel and laminated composite plates on the performance of the frequency for three stories shear walls with different

thickness of plates. Fig. 8. presents the comparison of steel and laminated composite plates on the frequency for three stories shear walls with different thickness of plates. Fig. 9. presents the effect of steel and laminated composite plates on the performance of the frequency for five stories shear walls with different thickness of plates. Fig. 10. presents the comparison of steel and laminated composite plates on the frequency for five stories shear walls with different thickness of plates. Fig. 11. presents the effect of steel and laminated composite plates on the performance of the frequency for ten stories shear walls with different thickness of plates. Fig. 12. presents the comparison of steel and laminated composite plates on the frequency for ten stories shear walls with different thickness of plates.



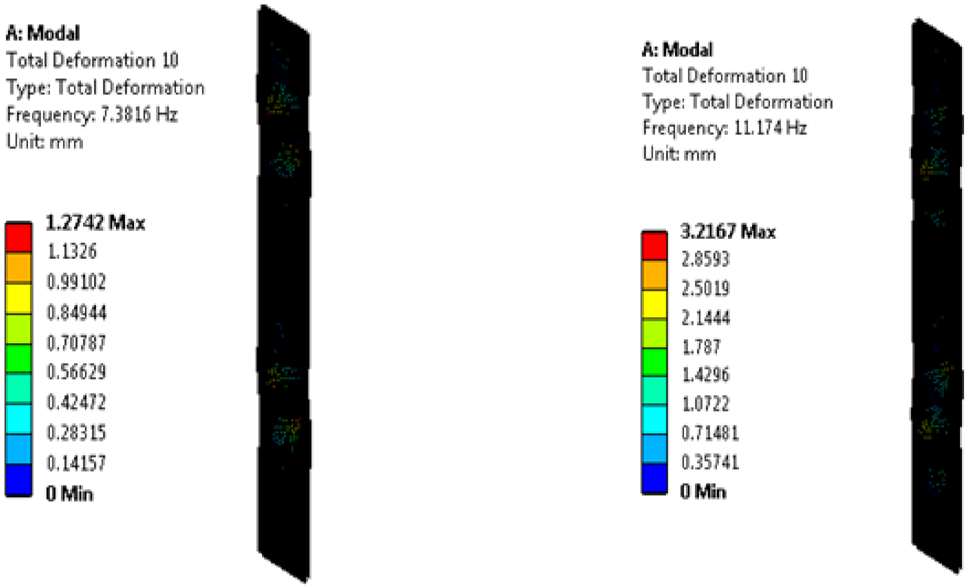

Steel plate Laminated composite plate

**Fig. 4:** Mode shape 1 for three stories steel and laminated composite plates shear walls with thickness of plates = 5 mm




Steel plate Laminated composite plate

**Fig. 5:** Mode shape 5 for five stories steel and laminated composite plates shear walls with thickness of plates = 8 mm




Steel plate　　　　　　　　Laminated composite plate

**Fig. 6:** Mode shape 10 for ten stories steel and laminated composite plates shear walls with thickness of plates = 10 mm

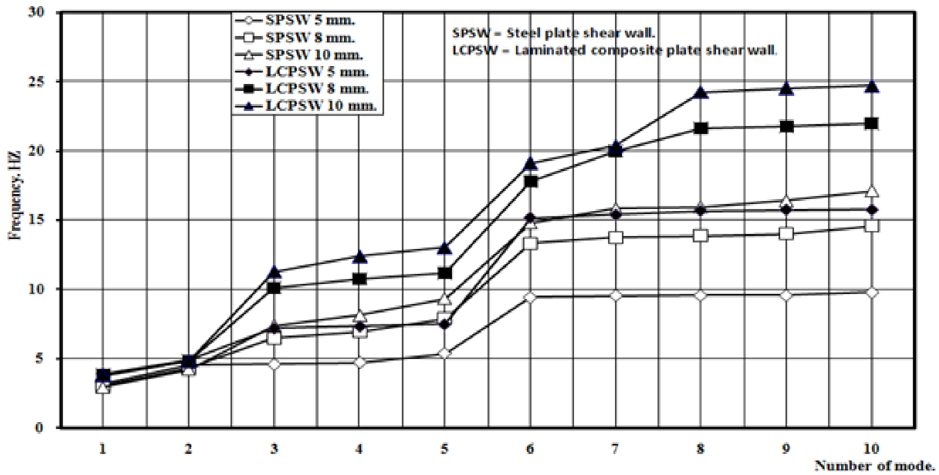



**Fig. 7:** Effect of steel and laminated composite plates on the performance of the frequency of three stories shear walls with different thickness of plates

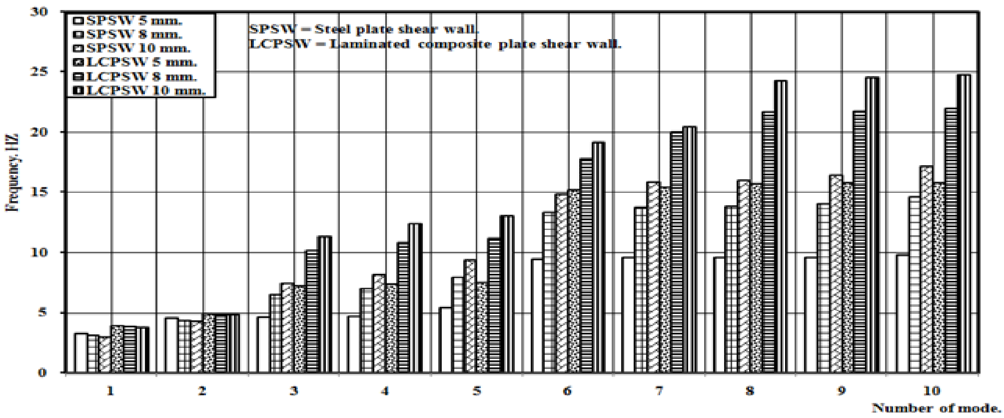


**Fig. 8:** Comparison of steel and laminated composite plates on the frequency of three stories shear walls with different thickness of plates

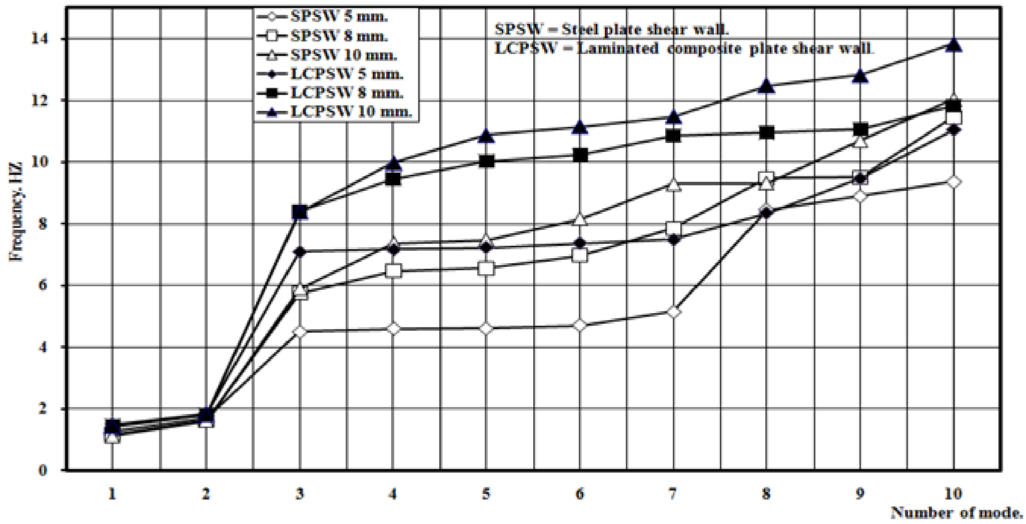



**Fig. 9:** Effect of steel and laminated composite plates on the performance of the frequency of five stories shear walls with different thickness of plates

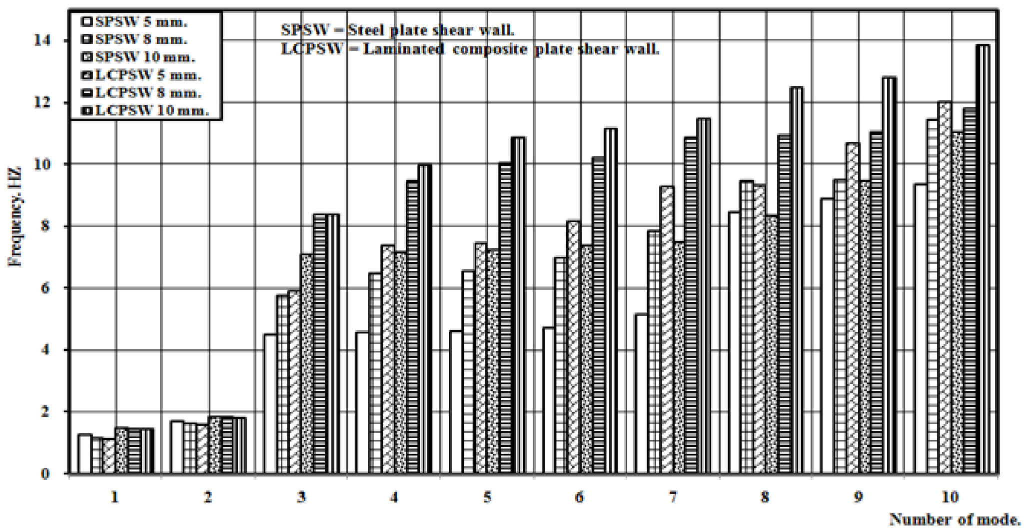



**Fig. 10:** Comparison of steel and laminated composite plates on the frequency of five stories shear walls with different thickness of plates

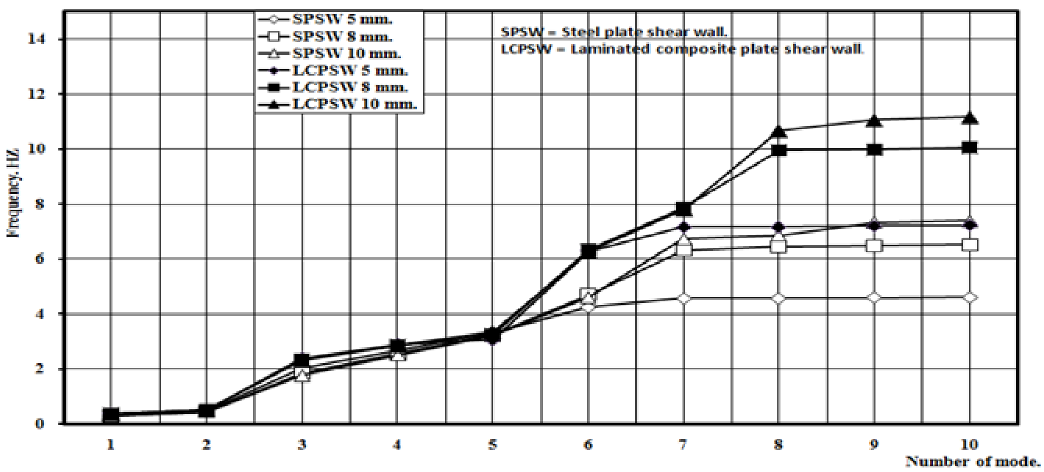


**Fig. 11:** Effect of steel and laminated composite plates on the performance of the frequency of ten stories shear walls with different thickness of plates

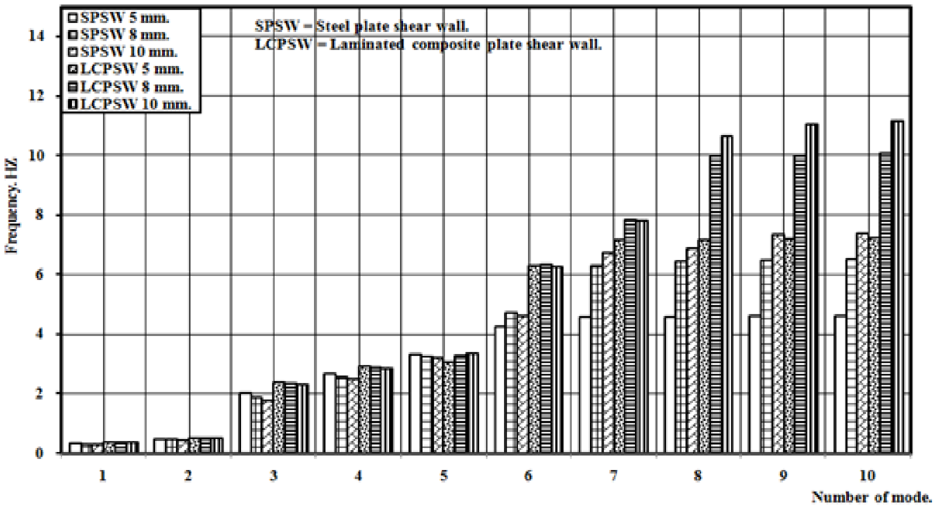



**Fig. 12:** Comparison of steel and laminated composite plates on the frequency of ten stories shear walls with different thickness of plates

From the previous figures, it is noticed that: In generally, for different number of stories, there is an increase in the natural frequency for shear walls with laminated composite plates when it is compared with the shear walls with steel plates with the increase of the number of modes. The natural frequency for laminated composite plate shear walls is higher than that for steel plate shear walls with the increase the thickness of plates and the number of modes. For laminated composite plate shear walls, the natural frequency has the biggest values when the thickness of plate equals 10 mm and it has the lowest values when the thickness of plate equals 5 mm with the increase of the number of modes.

**4-2 Effect of thickness of plates**

As the thickness of plates increases the natural frequency increases with steel and laminated composite plates shear walls for all number of stories with the increase of the number of modes as shown in Fig. 7. to Fig. 12. The natural frequency for laminated composite plate shear walls is higher than that for steel plate shear walls with the increase the number of modes for all number of stories. For three stories shear walls, the natural frequency for laminated composite plate shear walls with thickness of plate 5 mm is higher than that for steel plate shear walls with thickness of plate 8 mm with the increase of the number of modes. For five stories shear walls, the natural frequency for laminated composite plate shear walls with thickness of plate 5 mm is higher than that for steel plate shear walls with thickness of plate 8 mm for first six number of modes. For ten stories shear walls, there is no much variation in the natural frequency for steel and laminated composite plates shear walls with the increase the thickness of plates for first five number of modes and the natural frequency for laminated composite plate shear walls with thickness of plate 5 mm is higher than that for steel plate shear walls with thickness of plate 10 mm from six to ten number of modes.

**4-3 Effect of number of stories**

Fig. 13. presents the effect of number of stories on the performance of the frequency for steel and laminated composite plates shear walls with thickness of plate = 5 mm. Fig. 14. presents the comparison of number of stories on the frequency for steel and laminated composite plates shear walls with thickness of plate = 5 mm. Fig.15. presents the effect of number of stories on the performance of the frequency for steel and laminated composite plates shear walls with thickness of plate = 8 mm. Fig. 16. presents the comparison of number of stories on the frequency for steel and laminated composite plates shear walls with thickness of plate = 8 mm. Fig. 17. presents the effect of number of stories on the performance of the frequency for steel and laminated composite plates shear walls with thickness of plate = 10 mm. Fig. 18. presents the comparison of number of stories on the frequency for steel and laminated composite plates shear walls with thickness of plate = 10 mm.

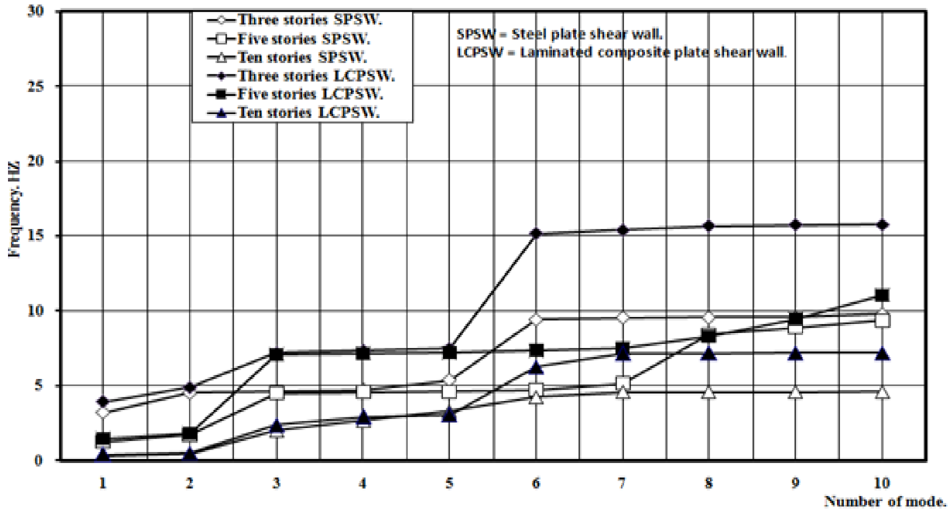



**Fig. 13:** Effect of number of stories on the performance of the frequency for steel and laminated composite plates shear walls with thickness of plate = 5 mm

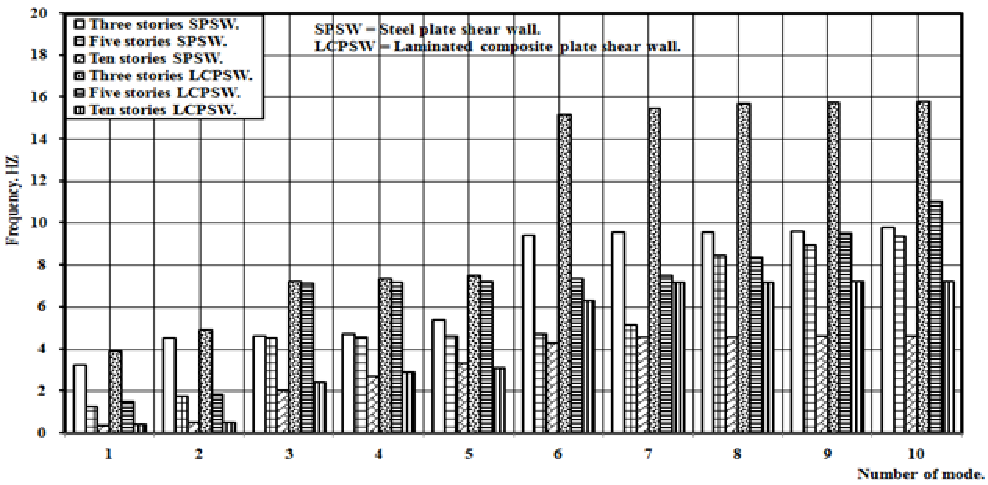



**Fig. 14:** Comparison of number of stories on the frequency of steel and laminated composite plates shear walls with thickness of plate = 5 mm

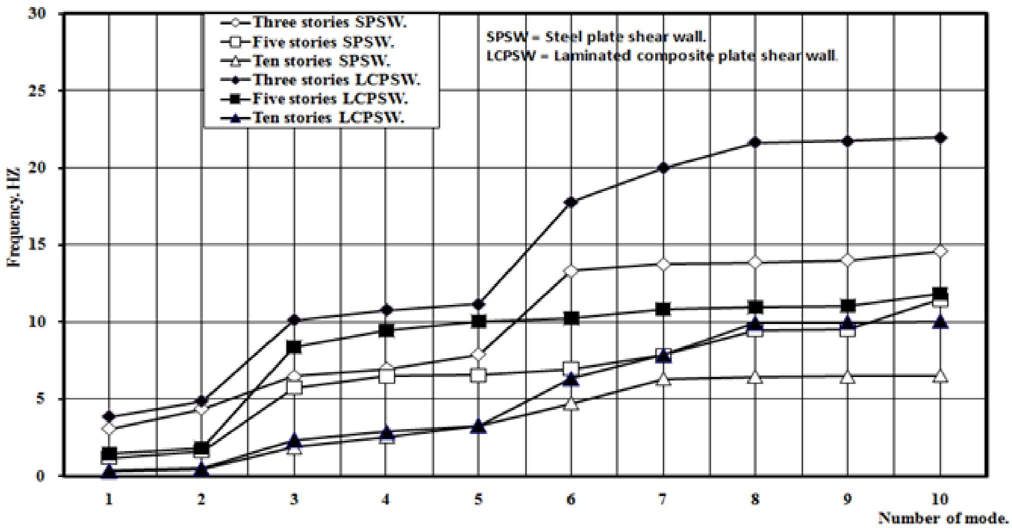


**Fig. 15:** Effect of number of stories on the performance of the frequency for steel and laminated composite plates shear walls with thickness of plate = 8 mm

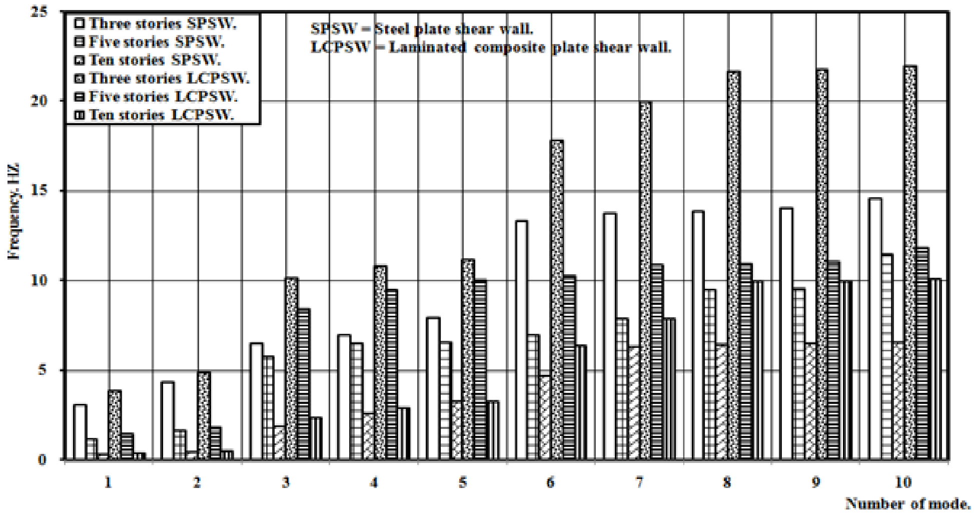



**Fig. 16:** Comparison of number of stories on the frequency of steel and laminated composite plates shear walls with thickness of plate = 8 mm

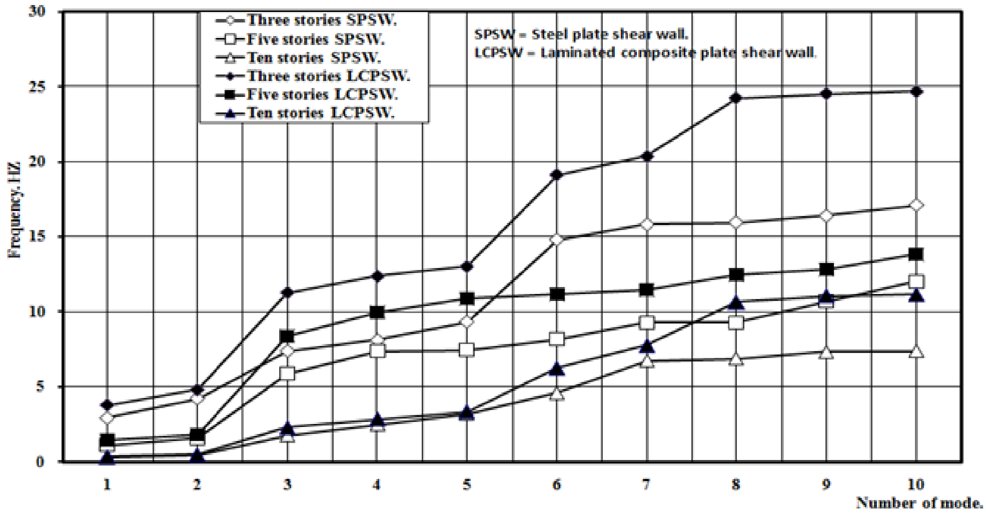



**Fig. 17:** Effect of number of stories on the performance of the frequency for steel and laminated composite plates shear walls with thickness of plate = 10 mm

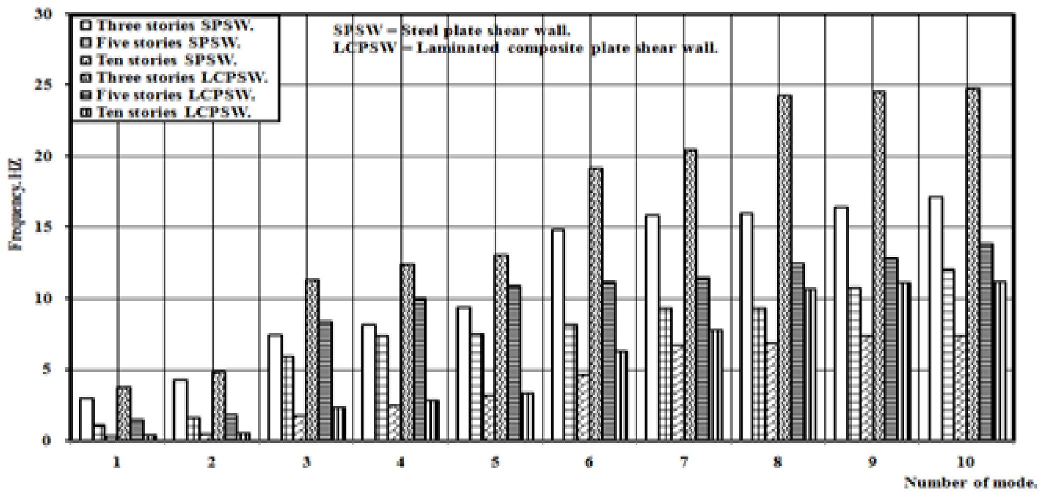


**Fig. 18:** Comparison of number of stories on the frequency of steel and laminated composite plates shear walls with thickness of plate = 10 mm

From the previous figures, it is noticed that:

In generally, as the number of stories increases the natural frequency decreases for steel and laminated composite plate shear walls with different thickness of plates. The natural frequency for laminated composite plate shear walls is higher than that for steel plate shear walls with the increase the number of modes for different thickness of plates. For laminated composite plate shear walls, The natural frequency has the biggest values with number of stories three and it has the lowest values with number of stories ten for different thickness of plates with the increase the number of modes.

## V. CONCLUSIONS

In this paper, the modal analysis of laminated composite plate shear walls has been done to investigate the free vibration response of laminated composite plate shear walls with compared to the performance of steel plate shear walls. From the results reported herein, the following conclusions are obtained:

1- Using laminated composite plates in shear walls has important effects on the free vibration response of shear walls with compared to the performance of steel plates shear walls which should be considered in design of shear walls.
2- The natural frequency for laminated composite plate shear walls is higher than that for steel plate shear walls with the increase of the number of modes, number of stories and thickness of plates.
3- For laminated composite plate shear walls, as the thickness of plate increase the natural frequency increase with the increase of the number of modes.
4- For laminated composite plate shear walls, as the number of stories increase the natural frequency decreases with the increase of the number of modes.

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