Parametric Study on the Structural Behavior of Honeycomb Sandwich Panel and Bridge Deck Applicability

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Abstract – Honeycomb sandwich panel is a sandwiched composite structure in which a honeycomb core is sandwiched between a top and bottom face sheet. Honeycomb core is a series of cells which is nested together to form a core. Top and bottom of this core is bonded to a top and bottom face sheet by an adhesive layer. The basic idea of honeycomb panel was to use the honeycomb as a shear web between two skins. It provides minimal density and high out-of-plane compression and shear properties. It has high strength to weight ratio and good impact resistance. Structural properties of honeycomb structure depends it's lower and upper face sheet thickness, the core material thickness, cell diameter, cell angle and foil thickness. Honeycomb cores are one of the most structurally efficient constructions, especially in stiffness-critical applications. Material used for the honeycomb construction also has very important in its structural performance

This study presents the static and dynamic analyses of honeycomb sandwich structures and their applicability in bridge deck constructions. The main objective of this study is to investigate the effect of geometric parameters such as lower and upper face sheet thickness, the core material thickness, cell diameter, and core configuration on the structural performance of the honeycomb panel. For this static analysis of panels were performed to find the deformation and shear stress with varying parameters. Mainly three core geometries square, hexagonal and rhombic were studied. The natural frequencies and mode shapes of sandwich structures fabricated with different configurations has been determined through modal analysis. Transient analyses were performed to analyse the effect moving loads on the deck panel with different core geometry and different material. The studies were performed with ANSYS 16 package.

Index Terms – Honeycomb sandwich structures, Glass Fibre reinforced polymer, Aramid fibre reinforced polymer, Carbon fibre reinforced polymer.

1. INTRODUCTION

Reduction of mass has always presented a challenge to the design engineer. This led engineers to look to more efficient structures. In 1938, a patent application went through for honeycomb manufacture, by a company in the U.K called Aero Research Limited. The basic idea was to use the honeycomb as a shear web between two skins. At this stage the adhesive technology was not yet sufficiently developed to bond skins directly on to honeycomb. The engineers, seeing the benefits of a lightweight expanded core with integral skins, carried on with the development of using end grain balsa as a core and plywood as skins to form sandwich panel. This particular sandwich or bonded structure was used extensively on the Mosquito and Vampire Aircraft. The development of epoxy resin made possible the bonding of aluminium skins to aluminium honeycomb. This occurred in 1954. Since then many developments in the honeycomb field have been taken place. Honeycomb sandwich panels are now used in various applications of civil, aerospace, and mechanical structures because of their high strength-to-weight ratios and desirable acoustic properties. They are stronger, stiffer, lighter fire retardant, good impact resistant and give a much better surface finish.

Honeycomb structures can be widely used for following applications;

- Standard aluminium skinned panels can be used for brattice walls
- Standard aluminium skinned panels can used to replace inverted box rib sheeting, thus keeping labour costs down.
- Railway sleepers
- Mild or galvanised steel panels with aluminium cores can be used for skips or cages.
- Glass phenolic skinned, aluminium cored structures can used for light weight partitioning
- Light weight platforms.
- Pure aluminium honeycomb used as an absorber of energy.
- FRP and steel honeycomb panels can use for lightweight bridge deck.

Traditionally, most highway bridge decks were constructed with steel structures or reinforced concrete strucures. The lifespan of such materials can be greatly reduced by weathering. It is also affected by traffic, chemicals, and reduced maintenance. Transportation agencies have been trying to identify new, cost-effective, reliable construction materials. Fiber reinforced polymer (FRP) sandwich panel have exhibited in eliminating corrosion concerns while also achieving a longer lifespan without requiring frequent maintenance. An FRP bridge deck weighs approximately one-fifth that of a reinforced concrete bridge deck. The FRP sandwich panel is composed of two thin facings that are bonded to a thick core. These facings are typically comprised of materials that have a high strength and high Young's modulus.

Fig.1.1 shows a honeycomb sandwich panel. Sandwich structures usually consist of a pair of thin stiff, strong face sheet (faces facings or covers), a thick, lightweight core to separate the skins and carry loads from one skin to the other, and an adhesive attachment it is capable of transmitting shear and axial loads to and from the core. The separation of the face sheet by the core increases the moment of inertia of the panel with little increase in weight, producing an efficient structure for resisting bending and buckling loads.

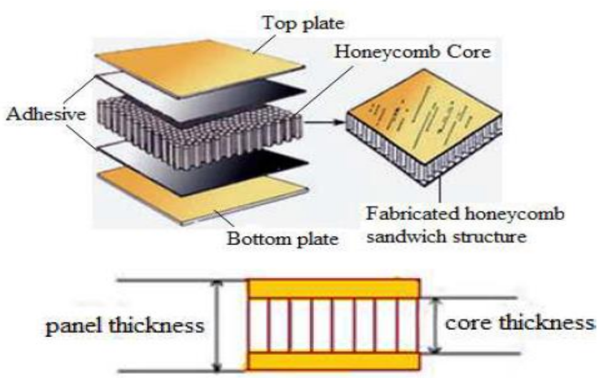

Fig.1.1: Honeycomb sandwich panel

The core geometry of this sandwich structures has influence on the stiffness and buckling responses by the continuous support of core elements with the face laminates. Different configurations of core such as square core, hexagonal core, rhombus core etc are performing differently. Hence, this study go through the parametric study of panel such as the effect of lower and upper face sheet thickness, core material thickness, cell diameter, cell wall thickness, and core geometry. The study also focuses on the structural behaviour of honeycomb sandwich composites panel used as bridge deck. Study looked for a suitable honeycomb core configuration and material combinations for honeycomb deck panel through numerical analysis.

2. RELATED WORK

A detailed study was given by By X. Frank Xu (2001) et.al for three typical honeycomb cores consisting of tubular, sinusoidal, and hexagonal geometry, and their solutions are validated with existing equations and numerical analyses. Prakash Kumar (2004) et.al, conducted Fatigue and failure tests on a 9.144 m long by 609.6 mm wide prototype honeycomb deck sample, equivalent to a quarter portion of the bridge deck. In this study provided the design of the bridge deck in detail. Guido Camata(2005) presented a study on the evaluation of the static performance of a glass fiber-reinforced polymer (GFRP) honeycomb bridge deck that was installed in O'Fallon Park.

The study showed that increasing the face thickness increases the flexural stiffness of a beam. Wahyu Lestari (2006) et.al did an analytical and experimental study on dynamic characteristics of honeycomb composite sandwich structures, which was made of E-glass fiber and polyester resins. Wahyu Lestari provided effective flexural and transverse shear stiffness properties of sandwich beams. Properties were along the longitudinal and transverse to the sinusoidal core wave directions. Gaetano G. Galletti (2008) et.al discussed the theoretical and quantitative design and analysis of a honeycomb panel sandwich structure.

The stresses in the panel exceed the properties of the materials by any mode, failure will happen. Wenchao Song(2011) et.al studied about the behaviour of honeycomb fiber-reinforced polymer (HFRP) sandwich structure with corrugated core geometry under the combined effects of service load and low-temperature cycling.

They concluded that the deflection limit span over 400 can be adopted in practice without any stiffness degradation because of interface debonding. P. Nagasankar et.al. (2015) investigated the effect of different orientations of fiber in the skins and different thicknesses of the skins and polypropylene honeycomb core (PPHC) on the transverse shear damping of the sandwich using experimental and theoretical studies. An impulse technique was used to calculate the natural frequency and loss factor of the composites M.P.Arunkumar (2016) et.al investigated that in honeycomb core sandwich panel the effect of face sheet thickness on vibration and sound radiation characteristics are significant.

3. PARAMETRIC STUDY

Modelling of a honeycomb sandwich plate was performed using finite element package ANSYS 16. In this study the honeycomb sandwich panel was modelled to study different parameters which affect the behaviour of panel. In the present study the parameters such as cell geometry, core height, face sheet thickness, cell wall thickness, cell size etc were studied by static analyses. Static analyses were carried out to find the deformations and shear stresses of panels. The honeycomb core is composed of flat Glass fibre reinforced sheets (GFRP) and bonded to corrugated GFRP core material. The material properties used for model was given in Table 3.1.

Table 3.1 Material properties

Materials	Properties	
GFRP	Density(g/cm^3)	2.1
	Poisson's Ratio	0.28
	Young's modulus (GPa)	45.21
	Shear modulus(GPa)	5.5

Based on the previous studies mainly three types of cell configuration for core were selected for the study such as hexagonal, rhombic and square were shown in the Fig.3.1.

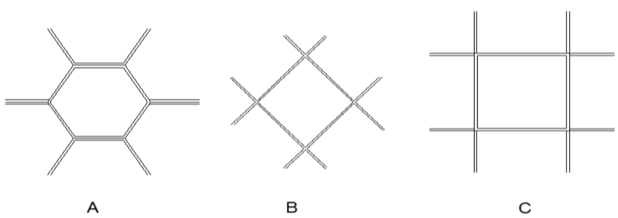

Fig.3.1: Unit cell of honeycomb with different configuration.

A) Hexagonal B) Rhombic C) Square

A typical honeycomb sandwich panel with length 115mm and width 85mm modelled in ANSYS16 and analyses were carried out. In this honeycomb core had a cell wall thickness of 0.025mm and cell size of 8mm. Panels with different core geometries were created in the ANSYS software to study the effect geometry. The models generated for different core honeycomb panel's were shown in Fig.2.2.

In order to study effect of parameters on the deformation and shear stress of the honeycomb core sandwich panel, static analysis of models were carried out. Parameters such as core height face sheet thickness, cell size, cell configuration, cell wall thickness etc were varied and models were created. The variations in the parameters used for the study was shown in Table 3.2. Configuration of the honeycomb core was varied as hexagonal core, square core, and rhombic core to study the effect of geometry. Static analyses of created models were done in ANSYS16. To present an efficient design for the panel, the mechanical behaviour of sandwich panels with different geometric parameters, including thickness of core and face sheets, panel height, cell size, cell wall thickness were studied.

The core was modelled as solid and face sheet was modelled as surface element. The panel was simply supported on shorter span. The boundary condition provided was simply supported in two opposite sides of plate along the shorter side. The load of 50N was applied on the centre of panel. Face sheet thickness of the honeycomb structure was varied for all 3core configurations. Like this the core height, cell size and cell wall thickness were varied.

Table 3.2 Variations in geometry for modelling honeycomb structure

Cell size	8mm	16mm	24mm	32mm
Face Sheet	0.5mm	1mm	1.5mm	2mm
Core height	5mm	10mm	15mm	20mm
Cell wall thickness	.025mm	.05mm	0.1mm	0.2mm
Core geometry	Hexagonal	Rhombic	Square	-

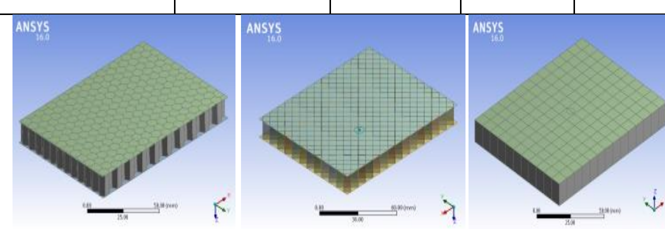

Fig.3.2: Model of honeycomb sandwich panels (Hexagonal, Square and Rhombic)

3.1 Effect of face sheet thickness

The face sheet thickness of honeycomb panel with hexagonal, rhombic and square core is varied as 0.5, 1, 1.5 and 2mm. The core height and cell wall thickness are kept constant as 15mm and 0.025mm respectively. Static analysis was done. Deformation and shear stress values are noted.

3.2. Effect of core height

Core height of honeycomb panel with hexagonal, rhombic and square core is varied as 5, 10, 15 and 20mm. The face sheet thickness and cell wall thickness are kept constant as 1mm and 0.025mm respectively. Static analysis was done. Deformation and shear stress values are noted.

3.3 Effect of Cell Wall Thickness

The cell wall thickness of honeycomb panel with hexagonal, rhombic and square core is varied as 0.01, 0.025, 0.05, 0.1and

0.2mm. The face sheet thickness and core height are kept constant as 1mm and 15mm respectively. Static analysis was done. Deformation and shear stress values are noted and tabulated.

3.4 Effect of cell size

The cell size of honeycomb panel with hexagonal, rhombic and square core is varied as 8, 16, 24 and 32mm. The core height and cell wall thickness are kept constant as 15mm and 0.025mm respectively. Face sheet thickness is kept as 1mm.Static analysis was done. Deformation and shear stress values are tabulated.

4. HONEYCOMB PANEL AS BRIDGE DECK

In this section, studies carried out on honeycomb sandwich panels used as deck slab. Honeycomb panel with different core geometry was analysed in ANSYS16 to find out best suitable geometry for bridge deck. Transient analyses were carried out to study the behaviour of panel and compared it with RCC deck bridge slab. Panel with different material combinations were modelled and analysed to find out best material for honeycomb panel.

Honeycomb sandwich panel with different materials and core geometry were taken for the analysis. In many literature reviews fiber reinforced polymer was used as bridge deck material. Hence in this study, Glass Fibre Reinforced Polymer (GFRP), Aramid Fibre Reinforced Polymer (AFRP) and Carbon Fibre Reinforced Polymer (CFRP) were selected as materials for modelling the honeycomb panel. From the previous studies in this area, the usage of steel with FRP materials can improves the stiffness of the structure. To study the influence of steel, panel with steel – FRP combination, that is steel as a face sheet and FRP as core were also modelled and results of different materials were compared. Firstly both the core and face sheet of panel were modelled with one of the three FRP materials. Then the face sheet of panel was modelled as steel and core was modelled as FRP material. This helped to compare the materials and effect their combinations. The material properties used for model was given in Table 4.1.

Table 4.1 Material properties

Material	GFRP	AFRP	CFRP	STEEL
Density (g/cm^3)	2.1	1.38	1.58	7.8
Poisson's Ratio	0.28	0.34	0.25	0.3
Young's modulus (GPa)	45.21	76	145	209
Shear modulus (GPa)	5.5	2.1	4.8	76

The loads imposed on the bridge decks include dead load, which includes the self-weight and weight of future surface wearing course, and the live load imposed in the form of wheel load. A uniformly distributed load of 10 kN/m^2 was taken as dead load for future wearing course on entire panel. These loads should be factored up suitably to account for impact and variation in material properties. The deflection produced by this factored load must be less than the limiting value of deflection. As per IRC 6 recommendation for single lane bridges Class A wheel load of 57 kN was considered as the live load. The deck panel were loaded to a factored load of 83 kN (wheel load of 57kN+30% of impact factor + DL of future wearing surface). The bridge deck panel was simply supported over shorter spans and a rectangular patch load that represents IRC Class A wheeled vehicle was applied over a patch area of 500 mm x 250 mm. The analysis was carried out in both static and vehicle moving condition.

In the case of a small bridge deck, the load limit was considered based on the lightweight vehicles passing over the bridge. The traffic pattern was assumed as a single lane at each direction with a total width of 6 m. For studying the behaviour of honeycomb panels as a bridge deck panel, a panel with width, length, and height 2120mm, 6000mm, and 107mm, respectively was selected. The geometry for the sandwich panel and load limits presented in this study was obtained from the experimental work accomplished by Mehdi Tehrani et al. [2015].

To reduce the complexity of geometry in the finite-element modelling (FEM) simulation, the size of the model was reduced by applying symmetry planes. As a result, a geometrical model with a lower number of elements was generated. This was leads to a lower numerical computation and a shorter processing time. Here, two planes of symmetry were applied to the sandwich panel on the longitudinal and transverse centrelines and divide the model into four equal sections. It has a size of width, length, and height as 1060mm, 3000mm, 107mm respectively.

To solve the moving vehicular load on the model, a transient analysis was used. Panels were modelled with different core configuration. A panel with solid core was also modelled and analysed. These results were compared with a concrete deck slab. Panel was simply supported in two sides along transverse direction.

Transient analysis was done to find out the effect of moving load on the honeycomb panel. Also, the time step size in each load step was specified to be 0.1s. Position of moving load on the deck at different time was shown in Fig.4.1.

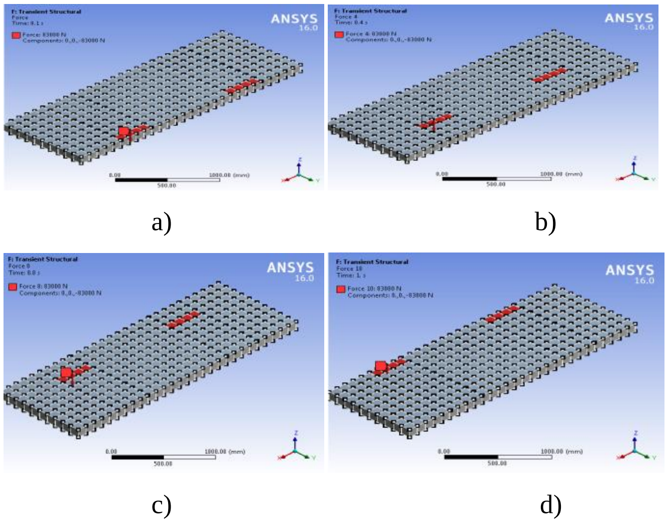

Fig..4.1: Moving load on deck panel at different time a) 0.1s b) 0.4s c) 0.8s d) 1s

5. RESULTS

5.1 PARAMETRIC STUDY

5.1.1 Effect of face sheet thickness

It was observed that, deformation decreases with increasing face sheet thickness. It was shown in Fig.5.1. It was due to increasing the stiffness of the structure with increasing face sheet thickness. Square shape had the least deformation in all face sheet thickness and rhombic shape has more deformation. Hence, rhombic shape had less stiffness than square and hexagonal shape.

Fig.5.2 showed that, shear stress decreases with increasing face sheet thickness. It was due to increasing the strength of the structure with increasing face sheet thickness. Square shape had the least shear stress in all face sheet thickness. So it had more strength.

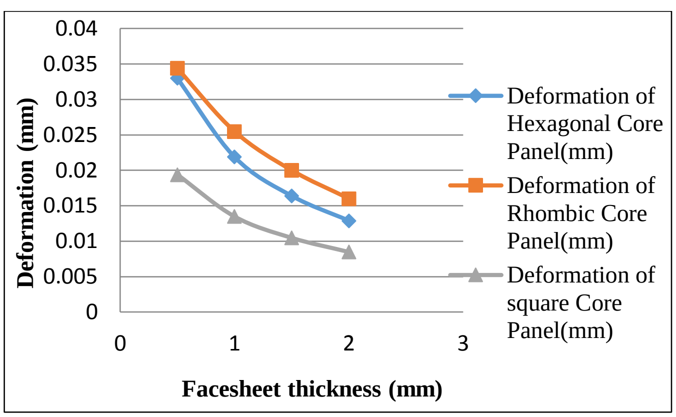

Fig.5.1: Deformation of honeycomb panel with varying face sheet thickness

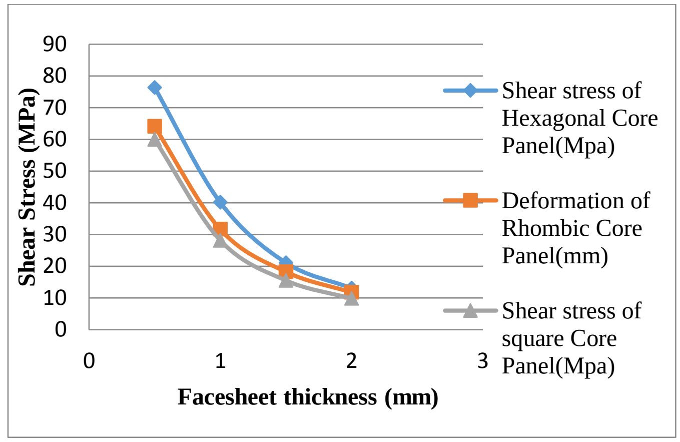

Fig.5.2: Shear stress of honeycomb panel with varying face sheet thickness

5.1.2 Effect of core height

Fig.5.3 showed that, deformation decreases with increasing core height. It was due to increasing the stiffness of the structure with increasing core height. Square shape had the least deformation in all core height and hexagonal shape had more deformation. Hence hexagonal shape had less stiffness than square and rhombic shape.

From Fig.5.4, it was observed that, shear stress decreases with increasing core height. It was due to increasing the strength of the structure with increasing core height. Square shape had the least shear stress in all core height. But core height had less influence in shear stress.

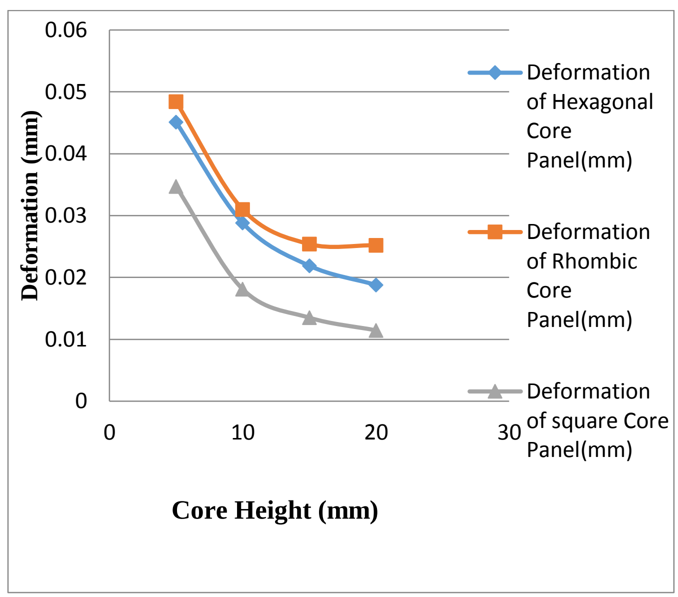

Fig.5.3: Deformation of honeycomb panel with varying core height

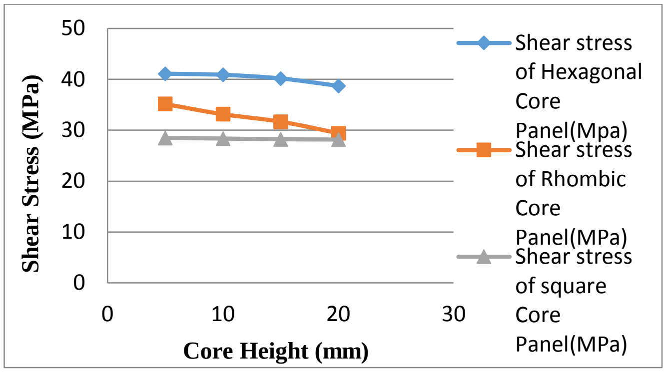

Fig.5.4: Shear stress of honeycomb panel with varying core height

5.1.3 Effect of cell wall thickness

Fig.5.5 showed the variation of deformation with cell wall thickness. When cell wall thickness increased, the value of deformation decreased. It was due to increase in the stiffness of structure with increasing cell wall thickness. The honeycomb panel with square shape got least deformation value at all cell wall thickness. From this it was clear that square shape has more stiffness compared to other geometry. But after a particular cell wall thickness the deformation was not much reduced.

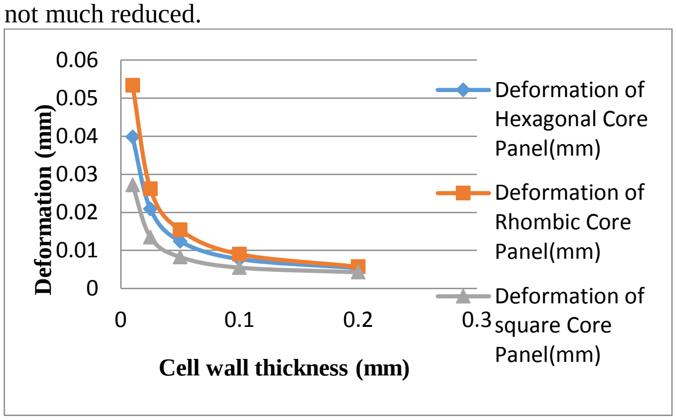

Fig.5.5: Deformation of honeycomb panel with varying cell wall thickness

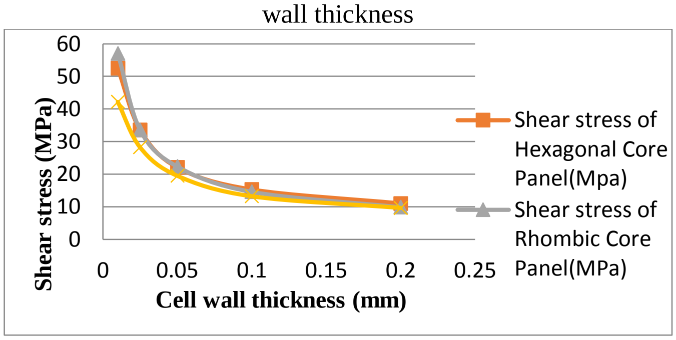

Fig.5.6: Shear stress of honeycomb panel with varying cell wall thickness

Fig.5.6 showed that, shear stress decreases with increasing cell wall thickness. It was due to increasing the strength of the structure with increasing cell wall thickness. Square shape had the least shear stress in all core height. Hexagonal and rhombic core had almost same shear stress in all cell wall thickness.

5.1.4 Effect of cell size

Fig.5.7 showed the variation of deformation with cell wall thickness. When cell size increased, the value of deformation also increased. It was due to decrease in the stiffness of structure with increasing cell wall thickness. The honeycomb panel with square shape gave least deformation value at all cell wall thickness. From this it was clear that square shape had more stiffness compare to other geometry.

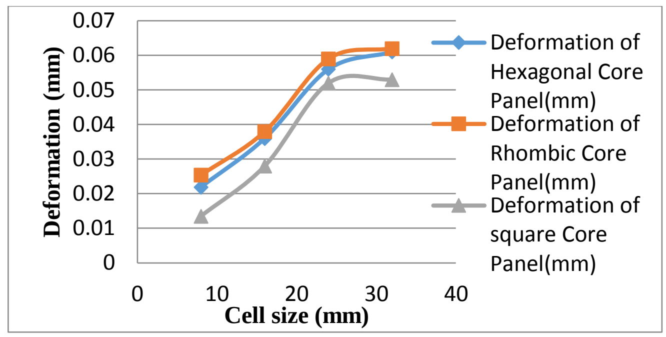

Fig.5.7: Deformation of honeycomb panel with varying cell size

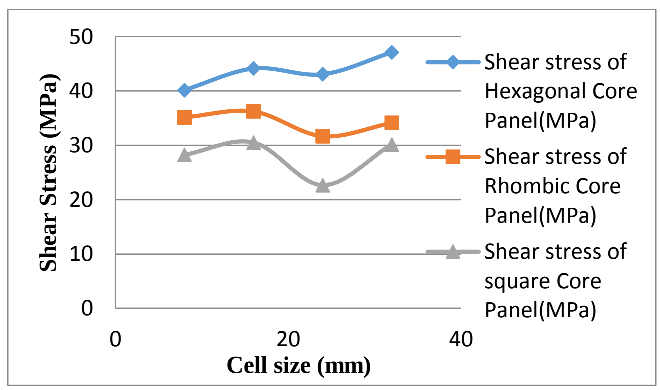

Fig.5.8 Deformation of honeycomb panel with varying cell size

5.2 HONEYCOMB PANEL BRIDGE DECK

Deformed shapes of honeycomb panels were shown in Fig.5.9. Shear stress distribution in the panel at time 1 second was shown in Fig.5.10

Deformation of honeycomb panel with different cores were compared. Honeycomb panel with FRP core and steel facesheet had very less deformation compared to the deformation of panel with FRP core and FRP facesheet. When GFRP honeycomb panel was replaced with a steel face sheet, it could achieve a deformation of CFRP honeycomb panel. It was suitable to use a GFRP with steel panel insted of costly CFRP mateial for panel.

When comparing the shear stress values of honeycomb panel with differnet materials the variations was found little. But the core geometry had influence on the shear stress of honeycomb panel. Panel with both FRP core and facesheet and panel with FRP core steel face sheet had almost similar shear stress values. The comparison of deformation and shear stress of the honeycomb panels were shown in Fig.5.11 and Fig.5.12

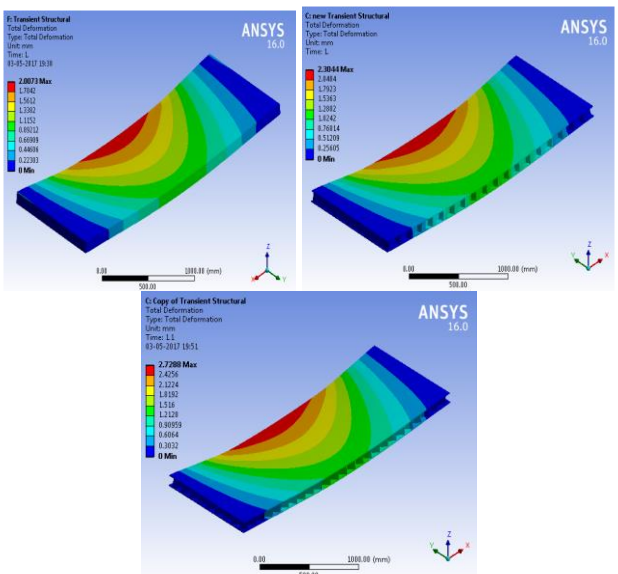

Fig.5.9: Deformation of square, hexagon and rhombic core GFRP panel in transient analysis

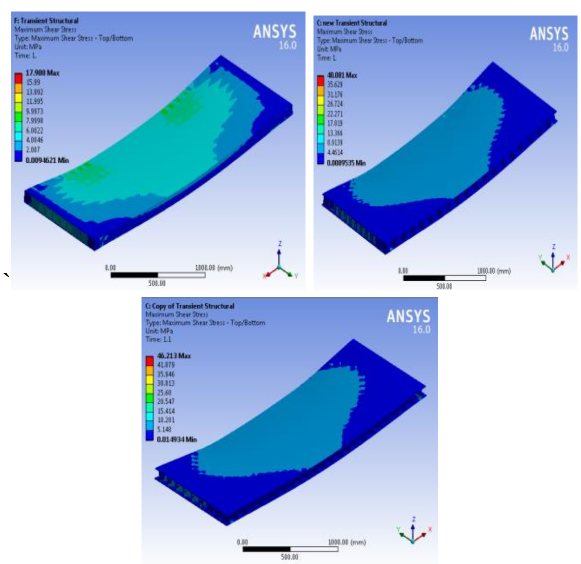

Fig.5.10: Shear stress of square, hexagon and rhombic core GFRP panel in transient analysis

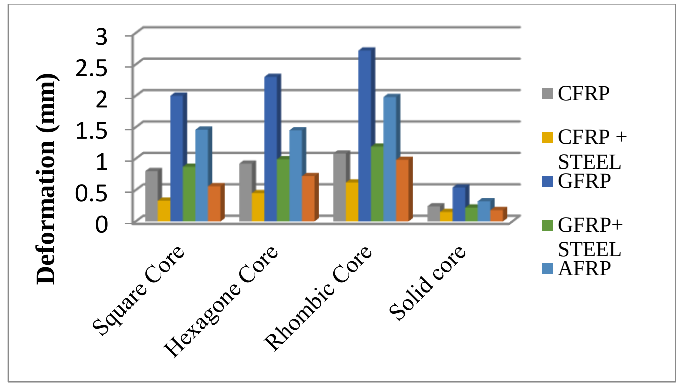

Fig.5.11: Comparison of deformation of panel with different cores (Moving load)

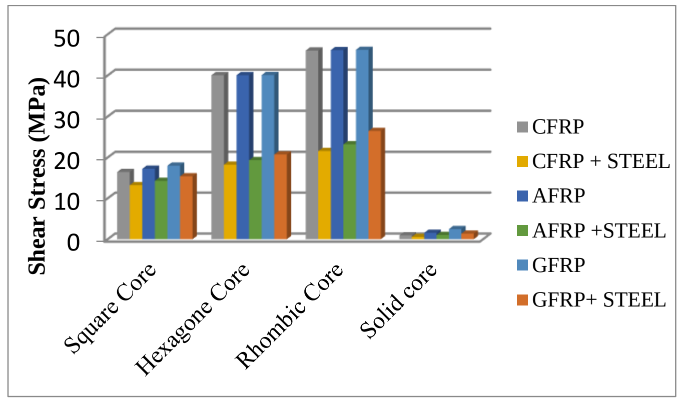

Fig.5.12: Comparison of Shear stress of panel with different cores (Moving load)

6. CONCLUSIONS

In this study an effort was taken to study the effect of various geometric parameters of honeycomb sandwich panel, on the structural behaviour of the panel. The study also compared the different core geometry of honeycomb sandwich panel and possibility of replacing a concrete bridge deck with a suitable honeycomb sandwich panel.

The following major conclusions were drawn based on the analytical studies carried out under this investigation.

- Deformation of honeycomb panel decreases with increasing, face sheet thickness, core height, and cell wall thickness. Hence, deformation of honeycomb panel decreases with decreasing cell size. Flexural stiffness of structure increase with increasing face sheet thickness, core height, and cell wall thickness
- Core height and cell size has not much effect on shear stress. But, face sheet thickness highly influence shear stress.
- From the study it is clear that square core has more flexural stiffness and strength than other two core configuration.

- Honeycomb deck panel with CFRP material has high strength among others due to its material properties. GFRP honeycomb deck panel also has good results in deformation and shear strength. But when comparing other two materials it has less strength.
- Stiffness of the FRP deck panel can improve by providing top and bottom face sheet with steel.
- Honeycomb panel with GFRP core and steel face sheet had deformation of 0.87mm and a CFRP honeycomb panel had a deformation 0.8mm. Shear stress values of both panels were also almost same. Hence we can replace a CFRP deck panel with GFRP with steel deck panel.
- In modal analysis of deck panel, square core panel had highest frequency. Hence it has more stiffness.
- Concrete deck panel has deformation as 0.108mm. The honeycomb panel with CFRP core and steel face sheet has a deformation of 1.3mm. Hence in failure analysis both has a stress ratio less than 1. So the structure is safe. Both panel has good result in safety factor.

The study reveal that honeycomb panels structural behavior is mainly depends on its face sheet thickness and core height. Core geometry has less effect in the stiffness property of structure. By increasing the face sheet thickness and core geometry as in a desirable manor, we can improve the stiffness of honeycomb panel. This panel is good option to replace traditional concrete and steel deck panels which has high weight and corrosion. A honeycomb panel with GFRP material has enough structural property for bridge deck. So it can use as bridge deck panel. Its properties can improve by providing replacing GFRP face sheet by steel.

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