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FE MODELLING AND ANALYSIS OF TWO-WAY GFRP SANDWICH SLIM FLOORS

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Abstract -*Innovative flooring systems utilizing lightweight Glass fiber reinforced polymer composite materials may have the significant potential to offer both economic and performance benefits compared to conventional concrete and steel systems. However before widely adopted by industries, fundamental understanding of their mechanical behaviour is necessary. The key focus of this project is an investigation into the mechanical behaviour of a new two-way GFRP sandwich slim floor system. The proposed new two-way GFRP sandwich slim floor system is in essence, a GFRP sandwich slab with GFRP beam. The sandwich slab assemblies were built-up sections made from pultruded web-core profiles incorporated between two flat panels, connected via adhesive bonding. A GFRP rectangular or I beam is provided as the beam and it is either partially encased or not. 3D finite element analyses are performed to provide detailed insight into the structural behaviour and to predict the deformation and failure loads. Different analysis such as static, impact, modal and buckling analyses are carried out and the performances are evaluated. GFRP sandwich slim floor with partially encased I beam with GFRP bars has high load carrying capacity and bending stiffness. Also it has better impact resistance. The fundamental natural frequency obtained from the FE analysis indicates better stiffness characteristics of the slim floor. All the buckling loads were higher than the maximum load carrying capacity of the GFRP sandwich slim floor. Hence, local buckling does not seem to be a crucial issue under the present loading conditions.*

Key words: **GFRP, Slim floor, Static, Impact, Modal, Buckling**

1. INTRODUCTION

Fiber-reinforced polymer (FRP) composites have been used successfully in civil engineering applications over the last several decades due to their favorable properties such as high strength and corrosion resistance. They also exhibit superior characteristics compared to concrete and steel, such as low thermal conductivity and lower life cycle costs. Conventional composite floor systems are having heavier and deeper beam sections. The architects and owners wish for greater flexibility in construction. This has led to more frequent use of slim floors. The main characteristics of this form of construction are a shallow floor in which beams and slab elements are integrated within the same depth. Also these are floors with a low structural height and large spans. These systems are composed of semi or fully prefabricated beams made of steel and steel reinforced concrete. To reduce the overall depth of the composite floor, the steel sections are normally fully or partially encased within the slab depth.

The focus of this thesis is to study the mechanical performance of two-way GFRP sandwich slim floors. The sandwich slab assemblies were built-up sections made from pultruded GFRP web-core profiles incorporated between two GFRP flat panels, connected via adhesive bonding. A GFRP rectangular or I beam is provided as the beam part and it is either partially encased or not. Finite Element models are developed to evaluate the deformation and failure loads. Different analysis such as static, impact, modal and buckling analyses are carried out on the GFRP sandwich slim floor and their performances are evaluated.

1.1 Methodology

Firstly a preliminary study was carried out on GFRP sandwich slabs by considering the parameters like box profile dimensions and its orientation, inclusion of core material. Then the load carrying capacity of GFRP sandwich slab is compared with conventional RCC slab with minimum reinforcement. A new two way GFRP sandwich slim floor was modelled with GFRP sandwich slab and I beam or rectangular beam with inclusion of core material and GFRP bars. Then a non linear static analysis was carried out on GFRP sandwich slim floors and to find out an optimum GFRP sandwich slim floor system. Optimum GFRP Sandwich slim floor model was then analyzed under various loading conditions such as Impact load, lateral load and buckling load.

2. PRELIMINARY STUDY

A preliminary study was carried out on GFRP sandwich slab to study its mechanical behaviour by varying different parameters like box profile dimension, its orientation, and inclusion of core material. Maximum load carrying capacity and the bending stiffness of the GFRP sandwich slabs are evaluated by non linear static analysis. Five different box profile dimensions considered are 50x50x4, 50x50x6, 80x80x6, 80x80x8, and 100x100x6mm. Different box profile orientations are 0 degree, 45 degree and 90 degree. The foam is included inside and outside box profile.

2.1 Description of specimen parameters

The sandwich assemblies were built-up sections made from pultruded web-core box profiles incorporated between two flat panels of dimension 500x1500x6 mm, connected via 0.5 mm thick adhesive bonding. Each sandwich slab had a span of 1.50 ×1.50m, and was supported on all four sides by steel rollers with a diameter of 30mm. The steel rollers allowed both longitudinal and transverse sliding. Flat panels were placed in the longitudinal slab direction (along the x-axis) and the loading is given by means of a steel plate having dimension 550x550x35 mm at the centre of the slab on the upper flat panel as shown in Fig 1. Araldite 420 epoxy adhesive was used as the adhesive connection. Divinycell P120 Foam was used as a core material. The material properties used for the present study are given in Table 1

Table -1: Material properties

Material properties of GFRP sandwich slab						
Properties	Flat	Box	Adhesive	Core	Plate	GFRP bar
Young's modulus (GPa)	32.2	31.7	19	8.52	210	550
Poisson's ratio	0.3	0.3	0.3	0.3	0.3	0.3
Yield strength (MPa)	362.5	393.1	28	2	250	1250
Density (kg/m^3)	1200	1200	800	120	7850	2170

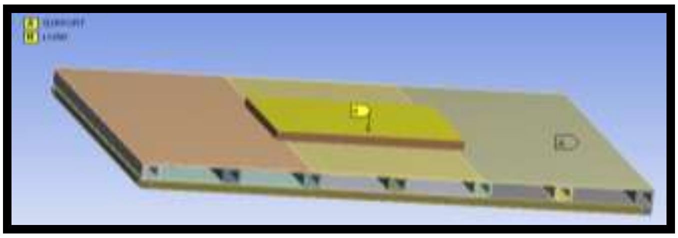

Fig -1: Modal geometry of the GFRP sandwich slab

2.2 DISCUSSION

Five different dimensions are considered such as 50x50x4, 50x50x6, 80x80x6, 80x80x8, and 100x100x6 .The results shows that the load carrying capacity of the slab increases with increase in profile dimension. Different box profile orientations considered are 0 degree, 45 degree and 90 degree. Slab with 0 degree Box profile orientation has better load carrying capacity and bending rigidity. The foam is included inside and outside box profile. Inclusion of foam outside box profile enhances the load carrying capacity and bending stiffness. Considering these effects GFRP sandwich slim floor is modelled and analyzed.

3. STATIC ANALYSIS

Non linear static analysis is carried out to investigate the fundamental structural behaviour under static loading on GFRP sandwich slim floors. Also the load carrying capacity and bending stiffness are evaluated.

3.1 MODELLING

Six different kinds of GFRP sandwich slim floors are modelled using ANSYS16.1. For static analysis, the size of finite element models can be reduced significantly through the use of symmetry, resulting in substantial computational savings. In order to make use of symmetry, both loading and structural configuration must be symmetric. Fig 2 shows the typical symmetric GFRP sandwich slim floor.

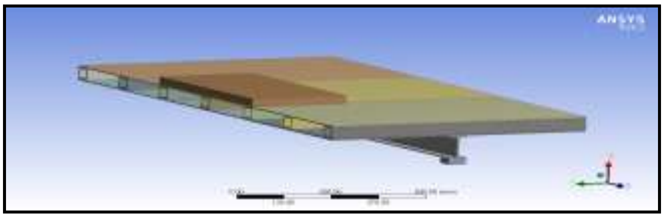

Fig-2: Symmetric GFRP sandwich slim floor

As shown in Fig 2, there is symmetry along both the length (the longitudinal axis, or x-axis) and width (the transverse axis, or y-axis) of the slab. The central loading used is also symmetric about both x- and y-axis. Thus, the entire slab structure can be modelled as a half, which significantly reduces the number of elements without sacrificing accuracy.

1.2 RESULTS AND DISCUSSION

A non linear static analysis was performed to investigate the fundamental structural behaviour of the two-way GFRP sandwich slim floor under static loading. The deflected shapes of the two-way GFRP sandwich slim floor for different sub models are shown in Fig 3.

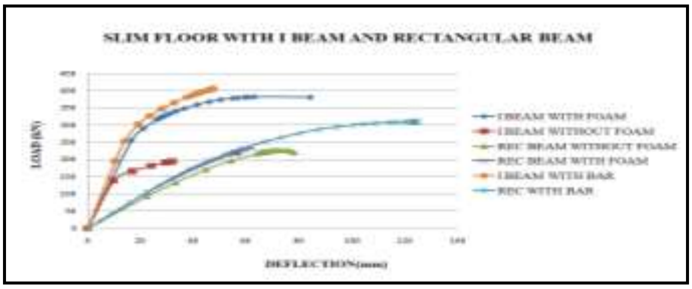

Fig-3: Load-deflection curve for GFRP sandwich slim floors

GFRP sandwich slim floor with partially encased I beam with bars has high load carrying capacity about 405.96 kN and its bending stiffness is about 8.51. The slim floor with rectangular beam has low stiffness than that of slim floor with I beam. The central deflection of optimum two-way GFRP sandwich slim floor is shown in Fig 4.

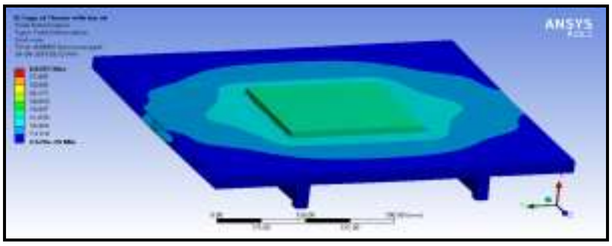

Fig-4: Central deflection of the two-way GFRP sandwich slim floors

4. IMPACT ANALYSIS

The response of a structure to an impact load is significantly different than to static and seismic loads. The duration of loading is very short leading to a comparatively higher strain rate. The modes of structural deformation and failure are also different leading to a much complex dynamic response making it difficult to analyze using traditional computational methods.

4.1MODELLING

ANSYS 16.1 software was used to numerically investigate the impact behavior of the GFRP sandwich slim floors. The model was analyzed under low velocity impact about 10 m/sec at a height of 5 mm above the upper flat panel of the GFRP sandwich slim floor as shown in Fig 5.

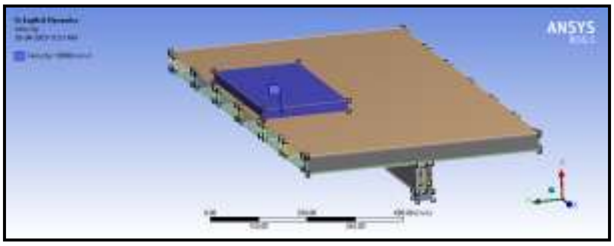

Fig -5: Simulation of load in impact analysis

4.2 RESULTS AND DISCUSSION

The results are presented in terms of impact load-time history and displacement- time history. Table 8.2 shows the impact force or load corresponding to the displacements and the impact load is calculated by using the following equations given below

Work done = Energy

Force x displacement =1/2 x mass x (velocity) ^{2}

Impact force = (1/2 x mass x (velocity) ^{2}*) / displacement*

- **Impact Force–Time History**

One of the most important data sets recorded during the impact test is the impact force. Fig 6 shows Impact Force–Time History graph

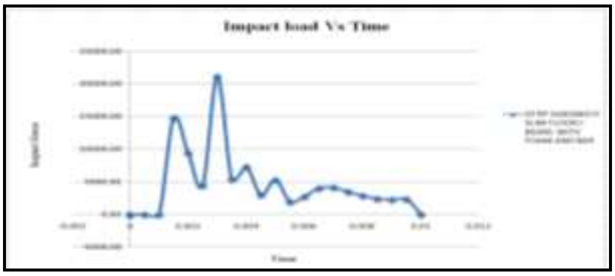

Fig-6: Impact Force–Time History graph

The impact force reaches a peak value in a short time and then the curve descends to zero gradually as the impact energy is dissipated. The duration from the first contact between the impactor and the specimen until the impact energy is dissipated (the specimen and impactor are separated) is called the impact duration. Here the impact duration is about 0.01 seconds and the peak impact load or maximum impact load of the GFRP sandwich slim floor is about 21103.31 kN. Fig 7 shows the deflected shape of the GFRP sandwich slim floor under impact load.

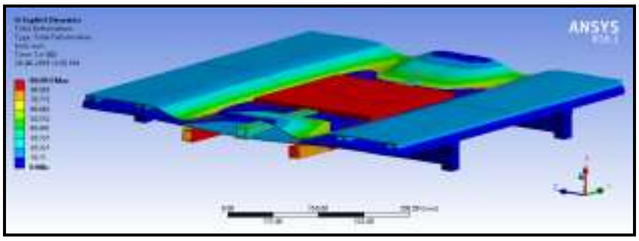

Fig-7: Deformation under impact load

5. MODAL ANALYSIS

Structures are subjected to various dynamic loads such as vehicular and earthquake loads. Hence, a calculation of the fundamental natural frequencies is of importance to the study of structural vibrations.

5.1MODELLING

In contrast with the static analysis, the full finite element model is often required for natural frequency analyses in order to determine all natural frequencies and corresponding modes. The analysis determines natural frequencies with corresponding symmetric modes. Thus, the fundamental natural frequency and corresponding mode of the optimum model GFRP sandwich slim floor was determined in this study. **Fig -8** shows the slim floor model used for the natural frequency analysis (modal analysis).

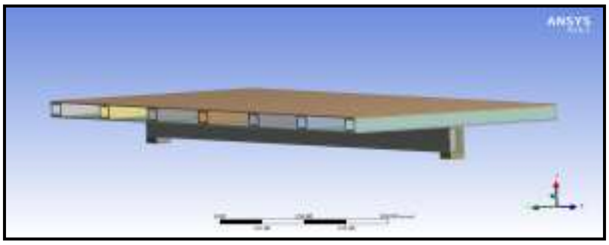

Fig -8: Slim floor model used for the modal analysis

5.2 RESULTS AND DISCUSSION

The first fundamental natural frequency and the time period of the slim floor are given below

Fundamental frequency = 185 Hz

Time period=0.005 sec

Fig -9 shows the deflected shapes of GFRP slim floor on first mode.

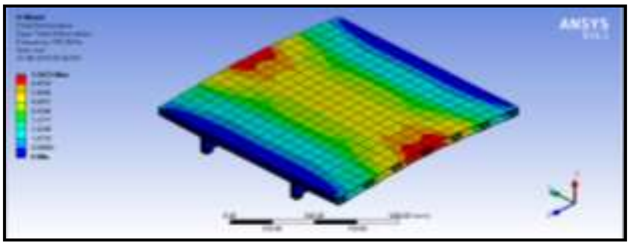

Fig -9: Deflection of slim floor on first mode

6. BUCKLING ANALYSIS

In general, global buckling is unlikely for a floor slab structure when the slab is subjected to an out-of-plane (along the slab thickness) load. This is also true for the two-way GFRP sandwich slim floor since the GFRP flat panels and box profiles are well bonded to the foam core. However, local buckling is possible within the composite slim floor in the thin walls of the box profiles. Thus, a finite element buckling analysis was performed in this study to provide an indication of the local buckling sensitivity of this two-way GFRP sandwich slim floor. It should be noted that the results obtained from this buckling analysis provide a guide to the significance of local buckling rather than an accurate estimation of the buckling load.

6.1 MODEL LING

In this analysis, only the first buckling mode was considered. As with the static analysis, the same boundary conditions and material properties were used in the buckling analysis. The load is provided by using a plate surface force with the magnitude of 1 N over a 550x550 mm2 area for the full model as shown in **Fig -10**.

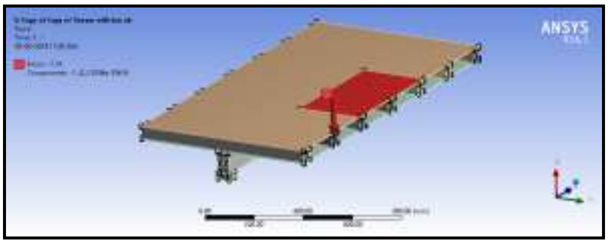

Fig -10: Simulation of loading in buckling analysis

6.2 RESULTS AND DISCUSSION

A linear Eigen value analysis was performed to obtain a first indication of the buckling behaviour of the GFRP sandwich slim floor. . Critical buckling load is about 671.6 kN. The first Eigen value calculated using the current model only represent a lower bound estimation of the buckling load **Fig -11** shows the buckling mode of the two-way GFRP sandwich slim floor.

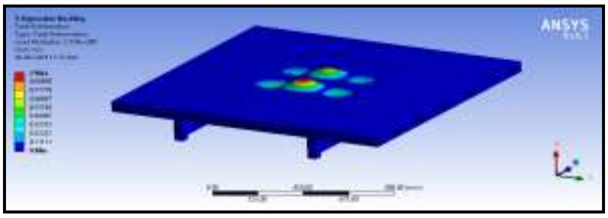

Fig -11: Buckling mode of GFRP sandwich slim floor

7. CONCLUSIONS

This paper has focused on the study of mechanical behavior of GFRP sandwich slim floors under various loading such as static load, impact load, structural vibrations and buckling loads. A preliminary study was carried out on GFRP sandwich slabs by varying box profile dimension, box profile orientation and inclusion of core material under static load by FE modeling and analysis. Based on the preliminary study the following conclusions can be drawn:

- The load carrying capacity of the slab increases with increase in profile dimension
- Large dimensions are not suggested due to economy and weight optimization
- Slab with 0 degree Box profile orientation has better load carrying capacity and bending rigidity than other orientations such as 45 degree and 90 degree
- Inclusion of foam enhances the load carrying capacity and the bending stiffness of the structure

Comparative study on Conventional RCC slab and GFRP sandwich slab shows that the GFRP sandwich slab has better load carrying capacity with less bending stiffness than that of RCC slab. Hence the bending stiffness of the GFRP sandwich slab is to be enhanced.

Different GFRP sandwich slim floors are modelled by including foam core and GFRP bars. The optimum GFRP sandwich slim floor obtained from the static analysis is further evaluated under impact, structural vibrations, and buckling loads. Based on these analyses following conclusions can be drawn:

- GFRP sandwich slim floor with partially encased I beam with GFRP bars has high load carrying capacity and bending stiffness
- Maximum impact load of the GFRP sandwich slim floor is about 21103.31 kN. i.e. the GFRP sandwich slim floor has better impact resistance
- The first fundamental natural frequency and the time period of the GFRP sandwich slim floor are 185 Hz and 0.005 sec respectively. The first fundamental natural frequency obtained from the finite element analysis indicates the better stiffness characteristic of the slab
- All the buckling loads are higher than the maximum load carrying capacity of the GFRP sandwich slim floor. Hence, local buckling does not seem to be a crucial issue for the GFRP sandwich slim floor under the present loading conditions
- Finite element analysis provides a relatively inexpensive, and time efficient alternative to physical experiments. However, it is vital to have a sound set of experimental data upon which to calibrate a finite element model

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