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SteFib ECC Built a Resilience Infrastructure

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Abstract. Sustainable Development Goals (SDG) 9 calls for resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation. Echoing this vision, construction industries have prioritised resilient structure and sustainable design while optimising economic and wealth growth. The use of steel fibre (SteFib) as scattered reinforcement in building design and construction had been explored. SteFib has been designed as reinforcement in the structural components of the building namely, raft foundation, floor and roof slabs, wall panel and column. Prototype of an Industrialised Building System (IBS) with two (2) bedrooms, one (1) living area and linked to a small kitchen was constructed using hook ended SteFib, 60 mm long and 0.7 mm in diameter mixed in grade 40 concrete. The prototype has successfully proven that the SteFib is able to stand as fully reinforced structure through this tiny home project. The structural performance analysed and verified using Autodesk Robot Structural Analysis. The analysis results show that steel fibre house has higher stress, forces and moment compared with normal concrete house.

1 Introduction

Generally known that steel fibers (SteFib) were added to concrete to improve the structural properties, particularly tensile and flexural strength [1]. SteFib has been used in concrete pavement since the 1960s and as additional reinforcement in the 1970s [2]. The extent of improvement in the mechanical properties achieved with Steel Fibre Reinforced Concrete (SFRC) over plain concrete depends on several factors, such as shape, size, volume, percentage, and distribution of fibers [1, 3]. Mixing SteFib considerably improves the structural properties, particularly tensile and flexural strength [1, 3]. Ductility and post cracking strength, resistance to fatigue, spalling of concrete and wear and tear of SFRC are higher than conventional reinforced concrete [3, 4, 5]. The performance of the hardened

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concrete is enhanced more by fibres with a higher aspect ratio, since this improves the fibre-matrix bond.

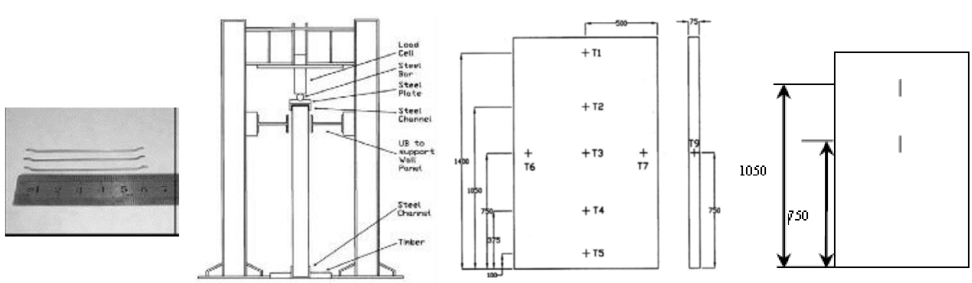
Core key is the durability, and it is in line with United Nation blueprint in Sustainable Goal Development (SDGs). Thus, make the industries focusing on construction technology in promoting the sustainability goal as main criteria in each project [3, 4, 5]. The roles of researchers are to innovate and invent in more advance design concept or material to produce high durability structure performance. SteFib was proven in show an excellent durability against corrosion as SteFib are considered as homogenous reinforcement in concrete [5]. In certain cases, the SteFib may show low effect towards corrosion compared to conventional reinforcement. As SteFib have smaller size and surface of area than conventional reinforcement [5]. Thus, SteFib seems to have better protected by the alkaline environment provided by the concrete [6]. A smaller cathode area on SteFib compared to the anode area is another argument for better resistance to corrosion.

1.1 Structural Element Design Proof

The preliminary stage involves structural element design proofs. The laboratory works have been carried out in the Heavy Structural Laboratory of Universiti Teknologi Mara Malaysia. The design works were carried out according to BS8110: Part 1. Hooked end steel fibres with tensile strength of 1200 Mpa; measuring 0.75 mm in diameter and 60 mm in length was used in this study.

1.1.1 Wall

Two wall panels had been prepared for this stage with aspect ratio (h/L) and slenderness ratio (h/t) of 1.5 and 20 respectively (refer Fig. 1). The size of the wall panel was 75×1000×1500 mm (thickness × width × height). The wall aspect ratio is L/d=80 and Figure 1 shows the hooked end steel fibre (SteFib) used. A 40 MPa concrete strength with additional 40 kg/m^3 fibre dosage which is equal to 5 kg of SteFib was used in each wall panel. The SteFib were added after all the materials were mixed at a rate of 20 kg/min while the drum mixer rotated at high speed for 5 minutes. This is very important to avoid fibres to clump together and become fibre ball. The compressive cube test was as discussed in previous research by Nurharniza [7].



(a) (b) (c) (d)

Fig. 1. (a) Hooked End Steel Fibre (SteFib); (b) The Experimental Setup, (c) The Position of LVDTs, and (d) The Position of Strain Gauges.

It is worth mentioning that Steel Fibre Wall Panel (SteFib$_{WP}$) only reach the yield stage as the test was stopped due to apparatus limitation before any apparent failure was exhibited by the specimen [8]. The results have shown that SteFib has help the wall (SteFib$_{WP}$) to sustain the static load with only minor cracks were observed near the support [8]. On the other hand, the normal reinforced wall panel (WFC_{WP}) were buckle at 0.75H (wall height) with major crack and concrete spalling within this buckle area. It shows that SteFib has help to improve the crack failure in wall panel. The distribution of SteFib in concrete in various directions helped to stop the cracks from further propagation [9, 10, 11].

1.1.2 Beam

The investigation on Steel Fibre Reinforced Beam had been done to investigate further on the sustainability beam with the present of SteFib as additional reinforcement [8]. These beams were named as Beam 1, Beam 2, and Beam 3. Concrete was designed for 30 MPa of concrete strength. At this stage fibre dosage was reduced to 30 kg/m^3. This dosage was reduced since the compressive cube test showed that this dosage also gives high compressive strength and for economic reasons [8]. Fig. 2 shows the detail specification of the beam.

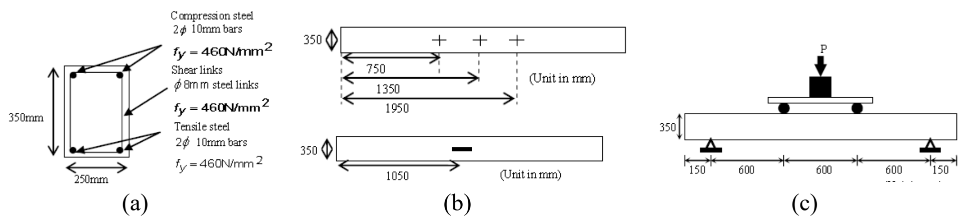


Fig. 2. (a) Cross Section Details; (b) The Position of Transducers and The Position of Strain Gauge; (c) The experiment setup.

Through the finding has shown that SteFib was found to be very efficient as shear reinforcement and give high resistance in cracking development behavior [9, 10, 11]. The beam was able to sustain higher displacement, higher ductility and energy absorption [3, 5, 7, 8].

1.1.3 Slab

The Steel Fibre Slab Panel ($SteFib_{SP}$) dimension was 1300×1000×75 mm and has then been tested under three point bending test. Fig. 3 shows the detailed diagram for the sample and test setup.

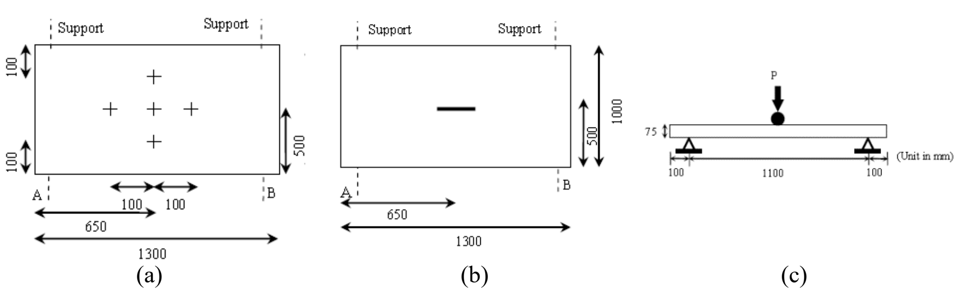


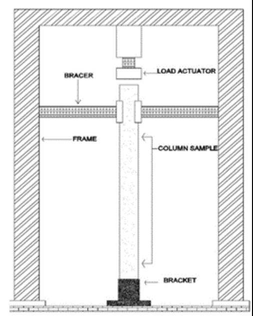
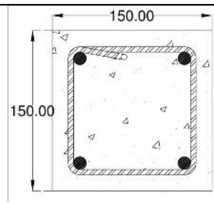
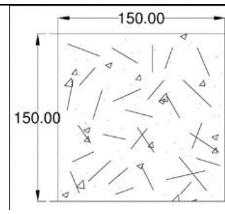
Fig. 3. The Schematic Diagram for the Experimental Set-up; (b) The Position of LVDTs and (c) The Position of Strain Gauge

SteFib was found to be efficient at improving crack control and deformation characteristics from the initial stage up to ultimate [3, 5, 7, 8, 9]. SteFib was also found to increase in the stiffness of the concrete performance and improved the resistance of concrete spalling. It showed that SteFib was working together with the reinforcement bar and exhibited large deflection failure, which is more than 50% compared to theoretical value [8].

1.1.4 Column

At this stage, the investigation was focus on the behaviour and characteristic of steel fibre (SteFib) in concrete column [4]. The investigation had identified in wide elements of characteristic such as mode of failure, crack pattern, deflection, deformation and ductility. Table 1 shows the detail dimensions of the samples.

Table 1. Dimension and experimental setup

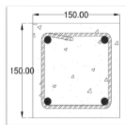
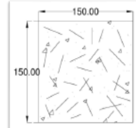
Name	Control sample	SteFib column	
Total of samples	6	6	
Cross section			
Bars	4Y12	-	
Link spacing	R10-100	-	
Concrete Grade	G40 (plain)	G40 + steel fibre	Experimental setup

The present of SteFib gives higher strength to sustain load with higher bearing capacity has provides more energy absorption to the column [3, 4, 5]. The geometry shape of SteFib helps to sustain the applied load besides have helps to sustain the column under compression load while help to prolong crack failure. Thus, it was proved SteFib increase the carrying capacity in concrete and reduced deflection when subjected to compression load. It is also helps to increase the durability and protecting the structural of column. SteFib help to control the deformation of column shape by improving the durability of samples [3, 4, 5].

In some cases when the column received more stress than control sample, but it is still can hold the reinforcement from buckling during the test [4, 5]. The randomly distributed SteFib in concrete can take part as a reinforcement to receive load before the load had been transferred to the main reinforcement. The visual observation shows SteFib concrete column had showed hairline cracks [4, 9, 10, 11]. It shows that the SteFib helps to disperse the crack and at the same time helps to sustain the column from failure. SteFib helps to hold the crack fragment on the surface from collapse. Thus, it is proven that the SteFib could withstand small crack from propagate further [4, 5].

On the other hand, the cost analysis and comparison were made based on the material used in conventional column compared to SteFib column. It was calculated that SteFib column has 70% of cost saving compared to conventional column [4, 5]. Details of calculation is shown in Table 2.

Table 2. Cost analysis and comparison

Conventional Column	SteFib Column
Size: 150 x 150 x 2000mm 	Size: 150 x 150 x 2000mm 
Main Bar 6T12 = 3m x RM3.50 x 6 = RM 63 **Link T8 – 200 c/c** = 0.45m x RM2.50 x 15 = RM 17 **Concrete Grade 30** 0.045m^3 x RM150 = RM 6.75	Use 25 kg/m^3 (1.5%) of **hooked end steel fibre as reinforcement** = 3kg Steel Fibre x RM6 = RM 18 **Concrete Grade 30** 0.045m^3 x RM150 = RM 6.75
Total Price : RM86.75	**Total Price : RM24.75**
Cost Comparison : 71.5% saving	

2 SteFib IBS House

Based on all element of structural design proof in section 1.1 [4, 5, 8], the prototype single storey house had been designed (Fig. 4) and built by using steel fibre as reinforcement for the whole structure. The implementation of the SteFib in Industrialise Building System (IBS) would give a better innovation in Malaysia specifically. At this stage, SteFib have been used for the whole part of the single-story house (refer to the layout plan as shown in the Fig. 4). It could be seen that the SteFib was able to sustain and carry heavy load compared to the reinforcement bar. Furthermore, by using SteFib to replaces the reinforcement bar have reduced the self-weight of the concrete structure.

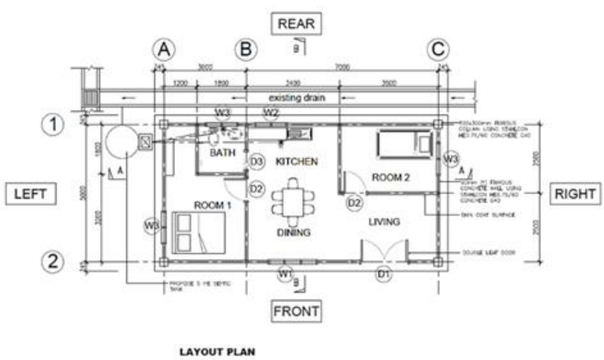


Fig. 4. Layout plan

2.1 Steel Fibre Reinforced Concrete Design

This single-story house was using fully steel fibre as reinforcement for foundation raft, column, walls, roof beam and roof slab. The construction has taken 25 days to complete the project. Concrete was design for grade 40 with usual, cement, sand and aggregate used in design mix and ordered from batching plan. While the SteFib were added to the concrete truck as an addition material on site. As a precaution to avoid SteFib to clump as fibre ball, SteFib was added in small amount at a time to the truck mixer. This experimental used hooked-ends steel fibre with the length about 60.00 mm and 1.00 mm of diameter (Fig. 5).

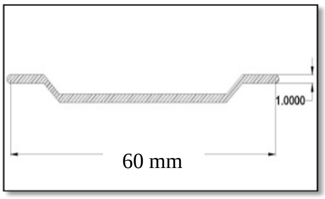


Fig. 5. Steel fibre (SteFib)

2.2 Steel Fibre Full Scale Prototype House

The preparation of the raft foundation took 3 days and this activity was conducted on the top of the asphalt road as shown in the Fig. 6. The concreting works for the raft foundation was the next step which the concrete mix design was included with steel fibre (Fig. 7).

Fig. 6. Preparation of raft foundation

Fig. 7. Concreting works for raft footing

The preparation of steel formwork erection took 5 days (Fig. 8). All structural design specification was followed according to British Standard (BS).

Fig. 8. Preparation for steel formwork erection

The IBS systems have been assembled according to the specification and design, the concrete mix with SteFib have used fully in each structural element. Fig. 9 and Fig. 10 shown the outcome of the structure component full scale SteFib IBS house has been built. The process of pouring the concrete took one day cycle for wall and column. The dismantling work of the steel framework was carried out after 24 hours of concreting. The roof slab of the single-story house took 3 days to complete.

Fig. 9. Dismantling work of steel formwork

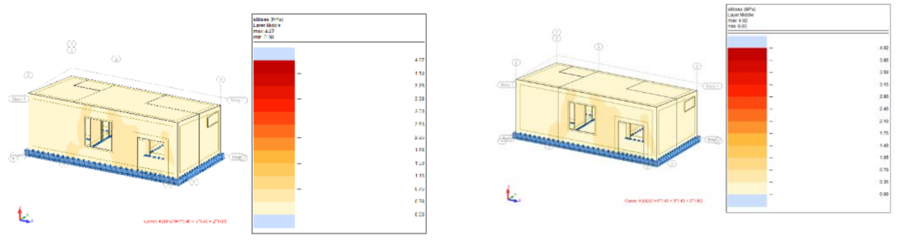
Fig. 10. Preparation of roof slab

On the 25th day the single-story house was completed. Fig. 11 shown below the condition of the single-story house and stand strong from 2015 to this date.

Fig. 11. The Up-Scaling Prototype Single Story House

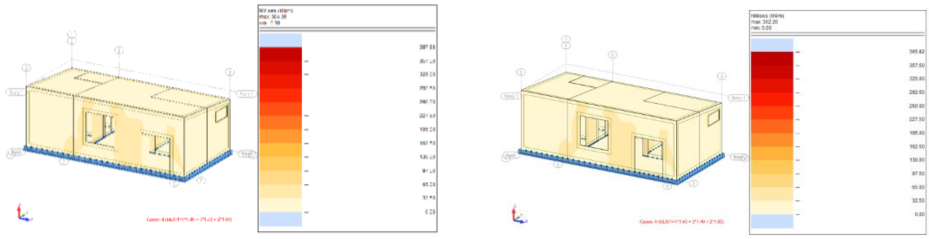
2.3 Steel Fibre Full Scale Simulation Analysis

The scope of the study for this research is to analysis the steel fibre single story house by using Autodesk Robot Structural Analysis (Fig. 12 to Fig. 15). In this analysis, all elements (columns, beams, slabs, walls and roofs) have been model using Autodesk Robot Structural Analysis. Concrete was design for grade 40 as this has commonly been used for Industrialise Building System (IBS) design.



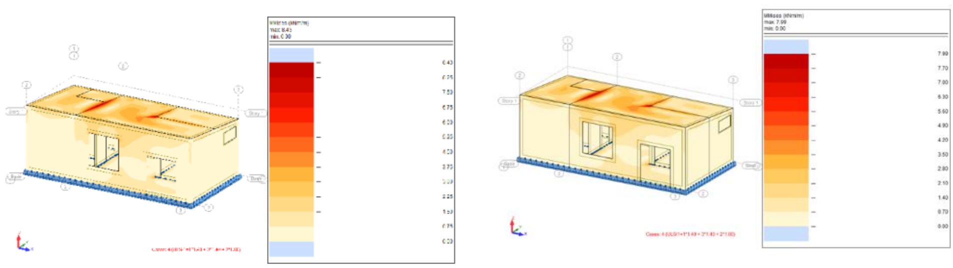
(a) (b)

Fig. 12. Stress Contour; (a) Normal Concrete House, (b) SteFib Concrete House



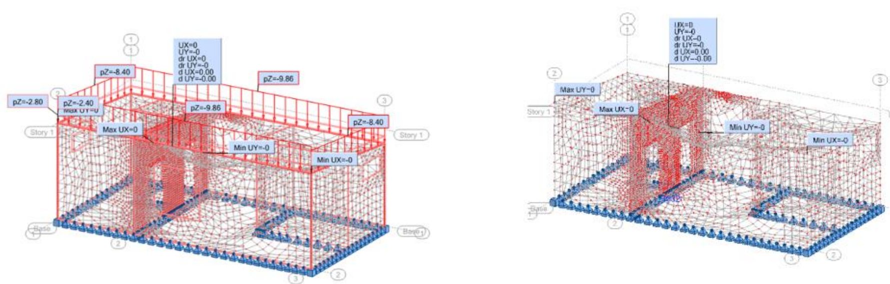
(a) (b)

Fig. 13. Force; (a) Normal Concrete House, (b) Steel Fibre House



(a) (b)

Fig. 14. Moment; (a) Normal Concrete House, (b) Steel Fibre House



(a) (b)

Fig. 15. Displacement Distribution; (a) Normal Concrete House, (b) Steel Fibre House

Maximum stress of normal concrete house and steel fibre house are 4.02 MPa and 4.27 MPa respectively. Steel fibre house's stress numerically 6.37%, which is higher than the normal concrete house. For forces and moments, steel fibre house takes less forces and moment which are 34.66 kN and 7.99 kNm respectively. Displacements of both houses are 0 mm, that's mean no deformation happened. Critical part is at joint and connection part. The result reveals that steel fibre functions well in improving performance of members resisting axial compressive load [3 – 8].

3 Conclusions

The outcome from this research has helps to conclude the new home concept of Industrialized Building System which in more efficient method with more sustainable and durable structural. The up-scaling field test has proven that the steel fibre concrete structure able to sustain as one main structure even though the hooked end steel fibre were using as full replacement to the reinforcement. Moreover, less labour needed to handle this type of construction since the structures were just reinforced with hooked end steel fibre except for the connection part and roof which required single layer of wire mesh A6 to strengthen the bending capacity. Through the analysis there is 70% of cost reduction for the steel fibre concrete column. Thus, the total construction cost also can be reduced since the reinforcement had been replaced with the hooked end steel fibre for the entire SteFib IBS house. Additionally, the duration of construction also had been reduced since this concept had used IBS concept for the construction. This structural innovation is in-line with sustainable development goal nine and eleven (SDG 9 and SDG 11). The SteFib house has built resilient, inclusive and sustainable infrastructure. It helps in promoting inclusive and sustainable industrialization through foster innovation structural. In overall it create an inclusive, safe, resilient and sustainable structural which has fulfilled the SDG 11 in United Nation (UN) blueprint goal.

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