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Bending Strength of Steel Fibre Reinforced Concrete Ribbed Slab Panel

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ABSTRACT

Nowadays, demands in the application of fibre in concrete increase gradually as an engineering material. Rapid cost increment of material causes the increase in demand of new technology that provides safe, efficient and economical design for the present and future application. The introduction of ribbed slab reduces concrete materials and thus the cost, but the strength of the structure also reduces due to the reducing of material. Steel fibre reinforced concrete (SFRC) has the ability to maintain a part of its tensile strength prior to crack in order to resist more loading compared to conventional concrete. Meanwhile, the ribbed slab can help in material reduction. This research investigated on the bending strength of 2-ribbed and 3-ribbed concrete slab with steel fibre reinforcement under static loading with a span of 1500 mm and 1000 mm x 75 mm in cross section. An amount of 40 kg/m steel fibre of all total concrete volume was used as reinforcement instead of conventional bars with concrete grade 30 N/mm^2. The slab was tested under three-point bending. Load versus deflection curve was plotted to illustrate the result and to compare the deflection between control and ribbed slab. This research shows that SFRC Ribbed Slab capable to withstand the same amount of load as normal slab structure, although the concrete volume reduces up to 20%.

Keywords: *steel fibre, ribbed slab, multiple ribbed slab*

INTRODUCTION

Reinforced concrete can be explained as a concrete that mixed with strong material such as steel which increase its strength under tension and make it less likely to fail. It is also a long-lasting building material that can be produced in various sizes and shapes. Its effectiveness and flexibility can be achieved by combining the best features of concrete and steel [1]. Due to the global changes in the economy, especially in the construction industry these days, it is observed that there are rapid increments in material price which at the same time causes the rapid hikes of the structure value especially those in urbanised areas. Therefore, it is important to find alternatives to reduce the quantity of material whilst constructing something that can carry the same function to the before-product.

However, in return of constructing a structure using less quantity of materials, there comes another concern related to its strength and capability to withstand load. Upon reducing the quantity of material for a structure, the strength of that particular structure will also reduce along with it. Due to the stated problem, fibre made of steel, glass and others are used to assist the structure. Different fibres have different characteristics, thus have different effects on concrete. Fibre reinforced concrete can effectively reduce the brittleness of concrete and improves its characteristics. Steel fibre is the commonly used fibre [2-3]. Steel fibre can increase the toughness of concrete as well as its resistance to impact.

Moreover, the cost of construction can be reduced when steel fibre is mixed in plain concrete [4]. With the addition of steel fibre, the ultimate load may increase up to 13% with a 3% reduction of displacement compared to normal concrete slabs [5]. During full-scale testing on the central loaded ground slab, it showed that the addition of steel fibre increased the load carrying capacity of the structure [6]. Steel fibre reinforced concrete is a concrete with added amounts of steel fibre [2][7].

Numerous researches have been conducted on the use of steel fibre on slab structures [5][8]. From previous research, hooked end steel fibre was found to be a suitable additional material to improve the performance of concrete such as mechanical resistance of concrete and ductility [9]. Steel fiber also improved the bond and anchorage of the steel fibres in concrete mixtures [10].

Strength and stiffness of structure depend on the strength and toughness of joint between layers. Therefore, ribs and other various shapes are included in order to help reduce the cost of the structure. The variety of design of the slab structure can reduce the concrete use up to 30% and give good strength [11]. Ribbed slab introduces void at the soffit to reduce its dead weight and increase the efficiency of the concrete section. With the variety of design such as ribbed slab and waffle slab, it is as an advantage in architectural design and also economic in term of material use [12]. Part of the benefit of ribbed slab is its lightweight nature. If the structure is lightweight, the support for the slab will also reduce, thus reducing the usage of material such as concrete for other structures such as beam and column. The ribbed slab can also provide extra strength in one direction of the slab.

In research done using finite element analysis, the behaviour of ribbed slab is similar to normal concrete structure. This is due to the addition of steel fibre in concrete mix [13].

The ribbed slab can also help in improving the aesthetical value of a structure. For example, instead of using the normal, rectangular slab, ribbed slab can be used as a substitute without losing the strength needed to give a fresh look to the old rectangular slab. Ribbed slab is seen as simpler in terms of design and also easier to cast on-site.

EXPERIMENTAL

Two-ribbed slab samples and one normal slab were cast in this work having the same concrete grade of 30 N/mm^2. Furthermore, the dimension of all the specimens were identical in term of size. Figure 1 shows the cross-sectional dimensions of the both SFRC, 2 and 3-ribbed slabs, and Figure 2 shows the plan view of SFRC ribbed slab with depth 75 mm by width 1000 mm and length is 1500 mm. In addition, because those slabs were ribbed slabs, there were voids created below the slabs. For two-ribbed slabs, there are

2-ribbed which each rib was made with a size of 37.5 mm by 335 mm and the size of the void is 37.5 mm by 200 mm in depth and width respectively. Meanwhile, for 3-ribbed slabs, there are 3 ribbed which each rib was made with a size of 37.5 mm by 200 mm and the size of the void is similar to the size of rib. All the ribs have same length as the slab which is 1500 mm.

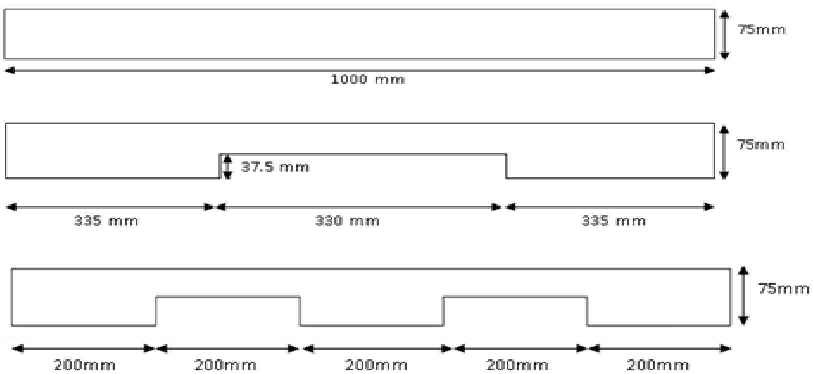

Figure 1: Control and Ribbed Slab Dimension (source by author)

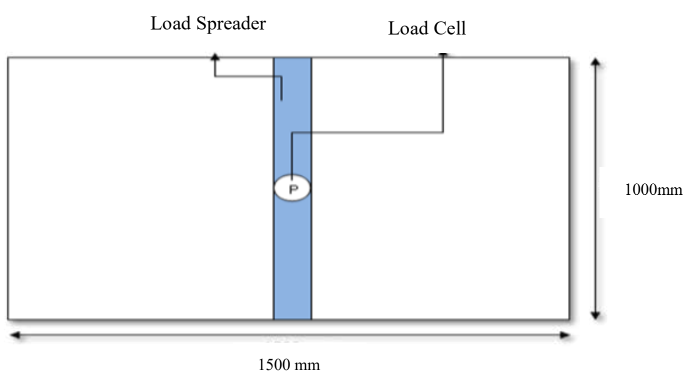

Figure 2: The Plan View of SFRC Ribbed Slab (source by author)

Mixing of concrete was done thoroughly to ensure that concrete of uniform quantity is obtained. For this study, the machine mixing was done in casting of concrete up to 0.1 m^3. Initially, the surface of formwork waslevelled and moist by oil. After that, the coarse aggregates were spread over the sand, and then the cement was spread over course aggregate. The mixer was operated up to two minutes for mixing until the colour of the mixture is uniform. Then, the water was added slowly while the mixer was operating until the mixture obtains proper consistency. The steel fibres were added last into the mixture gradually until it is well distributed.

Three Points Bending Test

Bending test was conducted to determine the strength of a material when bent over a given radius. Three point bending test is selected due to its simplicity and it is suitable to evaluate fibre reinforced concrete properties [13]. Using the universal testing machine, the slab was placed in the set-up to test its ultimate strength. One of the main advantages of three points bending testing is the ease of testing. Four LVDTs were placed at the centre, upper part and lower part of the slab.

Both Figure 3 and Figure 4 shows the placement of load in two types of view which used the three point load test using the machine. The load applied was gradually increased until the slab fails and the data logger recorded its ultimate strength. In addition, there were also four LVDTs used in this study for each specimen to obtain the displacement or deflection of concrete. The LVDT placed on both top and bottom surfaces of the slab, where each surface placed two of the transducers. Figure 5 shows the detailed locations of each transducer. Figure 6 shows the actual settings done at the Heavy Laboratory.

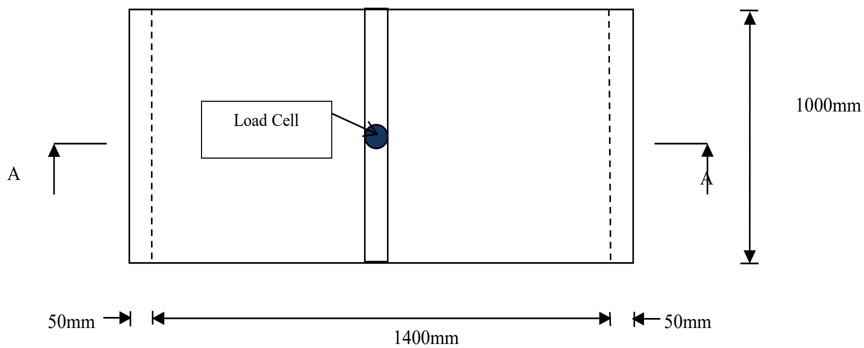

Figure 3: Plan View of Experimental Setup (source by author)

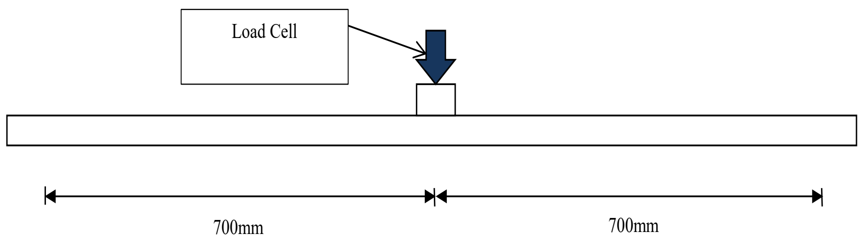

Figure 4: Side Elevation View of Experimental Setup (source by author)

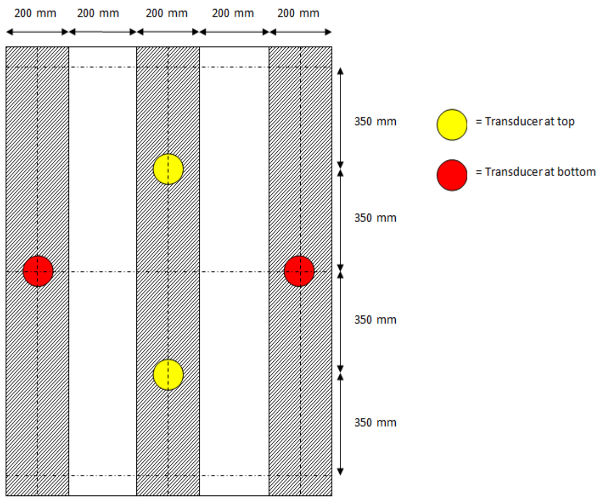

Figure 5: Position of LVDT (source by author)

Figure 6: Laboratories Experimental Setup (source by author)

Before testing, the dimension of the setup was carefully checked, and a detailed visual inspection made with all information was carefully recorded. After setting and reading all gauges, the load was increased incrementally up to calculated working load, with loads and deflections recorded at each stage. Loads were increased normally again in similar increments up to failure as well as deflection be recorded too.

RESULT AND DISCUSSION

Load versus Displacement

The results illustrated in Figure 7 show that the load has been increased up to its failure level, then, load and deflections for all the load steps wererecorded. Each slab shows different behaviour when the load was applied to them. Initially, there is a not much difference from both slabs when the load started to apply. But, the 2-ribbed slab shows it can cater much load at the beginning of the test compared to the 3-ribbed slabs. It is observed that the 2-ribbed slab behaved linearly elastic up to the value of around 5.97 kN higher 23.11% compared to the 3-ribbed slab recodring 4.59 kN where at this point, the minor cracks started appear at the tension face of the bottom slab. As the load further increases, the deflection started increasing with the load increment up to maximum load. The ultimate carrying capacity of the 2-ribbed slab is 6.2 kN when the deflection has reached to the value of 0.82 mm, while 5.97 kN and 4.81 mm of ultimate load and deflection for 3-ribbed slab respectively. After reaching the ultimate load, the value of load decreases as the slab losses its stiffness or the slab facing the softening stage.

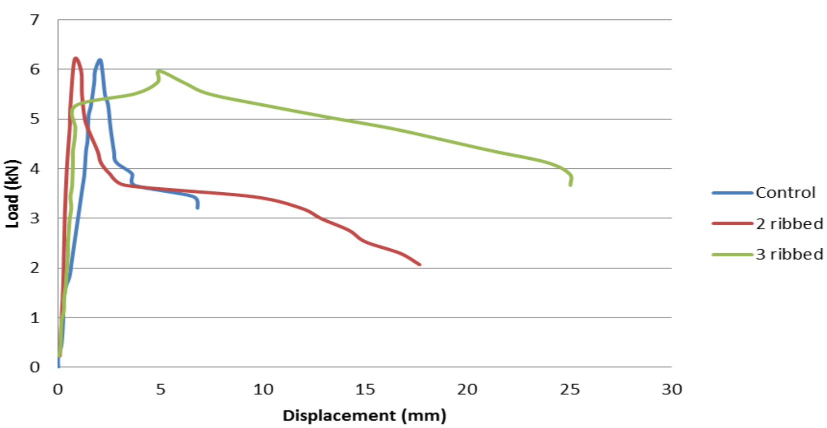

Figure 7: Load versus Deflection (source by author)

Table 1 tabulates the maximum load and deflection for control, 2-ribbed slab and also 3-ribbed slabs. The maximum deflection recorded from the test shows that control slab achieved the value of 2.04 mm of displacement at the highest load of 6.2 kN which behave similarly with 2-ribbed slab in term of maximum loading which is 6.2 kN with the displacement recorded is 0.82 mm. In the meantime, 3-ribbed slab recorded the maximum load of 5.97 kN and the deflection at maximum loading around 4.81mm.

Table 1: Maximum Load and Deflection

Sample	Maximum Load (kN)	Deflection at Maximum Load (mm)
Control	6.2	2.04
2-Ribbed	6.2	0.82
3-Ribbed	5.97	4.81

From the results shown in Figure 7 and Table 1, it is observed that the 2-ribbed slab behaved linearly elastic up to the value of around 5.97 kN higher 23.11% compared to the 3-ribbed slab marked 4.59 kN where at this point the minor cracks started to appear at the tension face of the bottom slab. As the load further increases, the deflection started to increase with the load increment up to maximum load. The ultimate carrying capacity of the 2-ribbed slab is 6.2 kN when the deflection has reached to the value of 0.82 mm, while 5.97 kN and 4.82 mm of ultimate load and deflection for the 3-ribbed slab respectively. After it reaches the ultimate load, the value of load decreases as the slab losses its stiffness or the slab facing the softening stage.

There are several factors that lead to the results. Firstly, the bonding between concrete and steel fibres affects the behaviour of slabs. Based on this study, the steel fibres functions well to extend or postpone the disintegration of matrix concrete because the tensile stress was absorbed by steel fibre. Furthermore, using of hooked-end fibre shows the effectiveness of elastic state of SFRC ribbed slabs. The hooked-end steel fibres tie the concrete effectively. During the elastic stage, the steel fibre plays an important role to maintain the concrete elastic behaviour longer than normal concrete [5]. In order for the SFRC to continue to carry the load and deform plastically after cracking has occurred, it is essential for the fibers to be sufficiently anchored in the concrete matrix to enable the full tensile strength of the fibres to be harnessed. Physical testing of steel fibres for pullout values has shown that 'hooked-end' fibres pull through as the ultimate fibre capacity is reached and this means the full capacity of the fibre is achieved over high deformations giving high-energy absorption and the characteristic ductility required to prevent brittle failure [5][9].

From the deflection magnitude, 2-ribbed slab is lower compared to 3-ribbed slab. Actually, this condition is unexpected condition where logically, the deflection will increase as the load increases. The reason of this is maybe due to the rib plays the role to control the deflection of the slab. So, the increasing number of ribs can reduce the slab deflection. In addition, because this slab is designed as ribbed slab, the depth of rib also can influence the deflection of the slab. The ribbed slab can act like a beam. The ribbed depth influences the slab deflection. In this study, the rib depth of both slabs is only 75 mm where the width of ribs is 200 mm and

330 mm respectively. Normally, the ratio depth over width is taken into account to design rib of the slab. Actually, the best range ratio d/b (depth/ breadth) is between two to three. The ratio became higher if the depth of rib increases. Unfortunately, for this test the slab cannot be designed with higher depth because the limitation of formwork for cast thicker slab. And also, if the ribbed depth increases, the rib can lead to shear failure. Shear crack can only be prevented by putting a shear bar inside the ribs. However, has not been experemente to avoid using any conventional bar for tensile and shear resistance. Perhaps, this slab can maintain the depth of ribbed, but the breadth of rib need to be reduced as close as to the best of d/b ratio. When the width of ribbed is smaller, the amount of concrete used also can be reduced. Indirectly, the self-weight of the slab can be kept low.

Visual Inspection

During the static load test, all the cracks formed were recorded. Loading was applied at mid span of the slab specimen. As the load increased, crack slowly appeared and its pattern visible to naked eyes. Crack patterns are one of the information that was observed.

From Figures 8, 9, and 10, it can be observed that each slab specimen displayed different crack pattern. For control and 2-ribbed slab, the crack pattern of the slab almost straight line as compared to the 3-ribbed slab which scattered along the neutral axis.

However, the crack for control appeared to be far from the neutral axis compared to the 2-ribbed slab when the crack drifted slightly away from neutral axis. This situation happened because of the uneven slab surfaces. When the load was applied, the crack started to disperse and propagated away from the neutral axis.

Figure 8: Crack Pattern of Failed Control Slab (source by author)

Figure 9: Crack Pattern of Failed Two-Ribbed Slab (source by author)

Figure 10: Crack Pattern of Failed Three-Ribbed Slab (source by author)

As compared to control and 2-ribbed slab, the crack width of 3-ribbed slab more deeper and wider. Due to the effect of steel fibres, the slab specimens did not break up completely. These fibres are usually used to control the effect of cracking and shrinkage, thereby it also improved its toughness. Fibre acts as crack arresters through the initial loading stage, and increase energy required for crack propagations, that provide the increase in strength [15].

CONCLUSION

Steel Fiber Reinforced Concrete (SFRC) can be one of the structural materials which has potential in the construction industry. The behaviour of SFRC ribbed slabs in this study showed that there is slightly different between normal concrete and ribbed slab in term of ultimate load carrying capacity and the magnitude of deflection.

The result shows that the steel fibre inside concrete plays important role to absorb more loads even though there is no reinforcement added. From the experiment, the load capacity from both slabs was found to be below 10 kN. But, if compared with normal reinforced concrete slab, this study proves the steel fibres can act as reinforcement for concrete structure. The following conclusions are drawn based on the experimental reselut tested on SFRC ribbed slabs:

a) The ultimate strength for 2-ribbed slabs is similar to control slab where the reduction of materials has resulted in both slabs behaves almost the same with the control slab. This shows that upon reducing the amounted materials, it only affects the strength of the material at a very small scale.
b) The SFRC 2-ribbed slab has greater 37.4% ultimate load capacity and lower 82.9% deflection compared to 3-ribbed slab.
c) Compared to the previous research using numerical analysis, the maximum load capacity of the same sample, it was found that the numerical value and experimental value is similar.
d) It is found that, steel fibre does effectively function as crack arrestor. This can be seen in the crack pattern on the failed ribbed slab.

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