Behavior of Prestressed Concrete Strengthened with and without SFRC Beams Subjected to Fatigue Loading

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Abstract

A substantial number of prestressed concrete structures such as bridge deck slabs, bridge girders, airport runways, or marine installations are often subjected to fatigue loading during their service life. These loads can result in a steady decrease in the stiffness of the structure and increases the risk of fatigue failure of prestressing strands through undergoing millions of cyclic loads. Use of steel-fiber reinforcement concrete (SFRC) materials for strengthening of structural members has become an increasingly popular area of research and application for concrete reinforcement in the last decade. However, very little work has been undertaken to determine their effectiveness for strengthening prestressed concrete. This experimental study is proposed to investigate the efficiency of using steel fibers to improve load carrying capacity and fatigue performance of prestressed concrete beam subjected to cyclic loading. Two prestressed concrete beam specimens of 180 mm in width, 250 mm in depth and 3500 mm in length were tested with steel fiber contents of (zero and 3 %) by volume of concrete, under constant amplitude cyclic and static loading. Based on the experimental results, it can be seen that the load carrying capacity of steel fibre increased by approximately 22% than the Plain prestressed concrete beam.

Keywords : *prestressed concrete, Steel fibers, Beams, Fatigue, Cyclic loads.*

I. INTRODUCTION

Structural members can fail under either static or cyclic loading. Since concrete structures such as marine structures, parking garages and bridges are subjected to repeated cyclic loading during their service life, it is important to understand and well defend their fatigue behaviour. These structures normally experience millions of stress cycles during their service life [2]–[20]. The repeated same basic reinforcing technique. Romualdi and Batson observed that the presence of closely spaced fibres resulted in an increased strength and retarded the formation of tensile cracks. By the addition of cyclic load can be detrimental to their structural performance.

Fatigue is referred to the weakening in materials or structures caused by repeated cyclic loading. From an engineering point of view, fatigue is important in terms of assessing existing structures and in designing new structures to sustain repeated cyclic loading before fatigue failure take place for a specified design life.

The need to understand fatigue arose after the industrial revolution introduced steel structures. A large number of tests have been performed to understand the fatigue phenomenon of plain, reinforced and prestressed concrete during 20th century [17], [18], [5]–[10]. The research results show that fatigue in concrete is characterised by: loss of stiffness leading to increased deflections, growths in crack lengths and widths, and increasing permanent strains. However, the influence of the fatigue process on the response of reinforced concrete is yet to be completely understood [4].

The fatigue process in reinforced concrete is more complex than plain concrete, as damage occurs in the concrete, steel reinforcing bar and the concrete-steel bond. In the recent years, the concrete fatigue phenomenon has gained interest, especially for railway bridges and bridge deck slabs due to more slender structures, higher traffic speeds and higher axle loads [5].

Steel-fiber-reinforced concrete (SFRC), a relatively new engineering material, can be used to enhance the fatigue strength of reinforced concrete. Steel-fiber-reinforced concrete has been developed through extensive research for over half a century [4], [6]–[7].

Steel and synthetic fibers have been used to enhance the properties of concrete in practice for many years.. The ancient Egyptians used chopped straw to the mixture of clay and pebbles during manufacture of sun-dried mud bricks to augment their strength [7]. In modern days - in the early 1960’s Romualdi and Batson [13] regenerated the fibers, the following properties of plain concrete are enhanced: tensile splitting strength, flexural strength, first cracking strength toughness, stiffness, durability, impact resistance, fatigue and wear strength increase, and deflection, crack width, shrinkage and creep decrease [2], [21], [4]–[15].

Steel-fibre-reinforced concrete (SFRC) is a composite material reinforced with discrete, uniformly distributed and randomly oriented fibres. The mechanical properties of quasi-brittle cement-based materials such as ductility, durability, energy absorption, fatigue and toughness can be improved by reinforcing with fibers [4], [12]–[15].

To evaluate the fatigue performance of SFRC many studies are conducted at material level and it is observed that steel fibres significantly improve the flexural fatigue strength due to its ability to limit crack growth and transfer tensile stresses. SFRC also achieves a higher deformation at failure compared to that of plain concrete [14]–[9].

While numerous testing has been undertaken for beams with steel fibres under static loading [8], [1]–[11]. the fatigue performance of SFRC at the structural level has not received much attention.

Based on the literature review, it can be seen that Steel-fiber-reinforced concrete (SFRC), a relatively new engineering material, can be used to enhance the fatigue strength of reinforced concrete. Steel-fiber-reinforced concrete has been developed through extensive research for over half a century . However, a lack of studies on prestressed Steel-fiber-reinforced concrete (SFRC), in fatigue applications. This paper examines the fatigue behavior of SFRC prestressed beams subjected to repeated cyclic loading. Two prestressed beams with and without fiber volumes were investigated. Both of beams, plain and SFRC, were tested until failure or until 2 million loading cycles were achieved, whichever came first. The results of the study are reported herein.

II. MATERIALS AND METHODS

Two prestressed beam samples were cast. The beam dimensions were 3500 mm in length, 250 mm in height, and 180 mm in width, as shown in Fig. 1. Beams were simply supported over a length of 3300 mm centre to centre and subjected to two equal central loads, spaced 500 mm apart, to produce a constant moment region in the middle of the beam. The main parameter in the testing program was the type of concrete (plain concrete and Steel fibre reinforced concrete).

In order to avoid shear failure and ensure a flexural failure, transverse reinforcement in the form of 8 mm diameter stirrups spaced at 100 mm centre to centre was provided within each shear span located on either side of the constant moment region. Four 10 mm Grad 420 deformed steel bars (two in compression zone and two in tension zone) were also used in the shear-spans. No transverse

Two concrete mixtures were used in this research : plain concrete and SFRC. The mixture proportions are reported in Table 1. The mixes were identical for the two specimens, except for the increase of the superplasticizer content in SFRC specimen in order to ensure a proper workability.

Steel fibre reinforced concrete specimen consist of 3% steel fibres by volume of concrete. Steel fibres used in the study was Dramix ZP 305, hook-end type have tensile strength of 1345 MPa, aspect ratio (length of fibre to its diameter) of 60, length of fibres of 30 mm and diameter = 0.55 mm.. A photograph of the fibers is shown in Fig 2.

Prestressing of plain and steel fibre reinforced concrete is done . Seven-wire strand has a diameter of 11 mm was used in the present study. The average eccentricity maintained was 47.5 mm. Both of the prestressing specimens were designed to have the same prestressing force Pu = 53.93 KN and amount of prestressed steel (74.2 mm2). The prestressing strands were tensioned using a single strand hydraulic jack a day prior to casting. The strand force was calculated by the elongated length of the tensioned strand as well as by a pressure transducer installed on the hydraulic jack. The tensioned strands were locked on steel abutments using barrels (male and female cone) in the prestressing yard. After three days of casting beam specimens, a gradual tension transfer procedure to concrete was used to cut the prestressed strands by a mechanical cutter simultaneously.

Load was applied using hydraulic jack up to the failure of specimen and the crack patterns were observed. At each load increment, cracks were inspected and marked and the beam specimens were photographed. The Experimental setup for the prestressed beam under fatigue loading conditions is given in Fig 3.

TABLE 1. CONCRETE MIXTURE PROPORTIONS.

Materials	Quantity (kg/m3)	
	PC	SFRC
Cement (PC 42.5)	400	400
Sand (0.44 mm)	900	900
Fine aggregate (4-16mm)	440	440
Coarse aggregate (15-25 mm)	580	580
Steel fiber	-	77
Water	200	220
Superplasticizer (Glenium ACE 30)	-	1.3

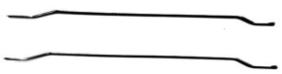

Fig 2: Steel fibers used.

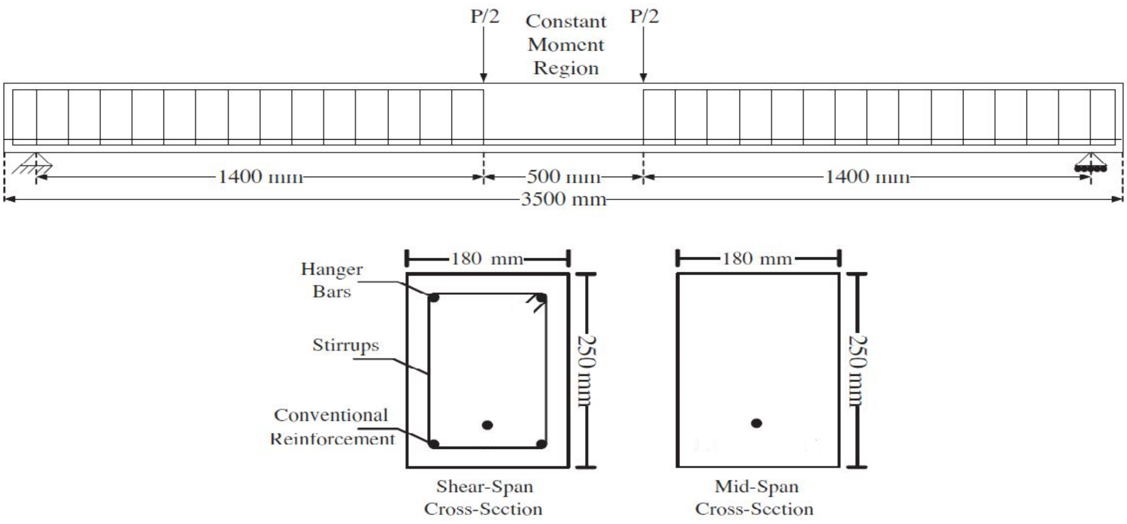

Fig 1: Prestressed concrete beam specimen.

Fig 3: Experimental setup.

III.RESULTS AND DISCUSSION

Two beam prestressed with and without SFRC system were tested under fatigue loading conditions. Due to the initial static loading cycles, used to determine the effective prestress force, two flexural cracks were observed at mid span at spacing approximately equal to the distance between the mild steel stirrups. After the initial loading, the beams were cycled and survived 2 million cycles.

During cyclic loading, as the cycles progressed, deflections increased. This is because of degrading stiffness with increased cycles. For both beams, the deflections increase at a low rate. The mid-span deflections under maximum load for plain prestressed concrete beam and prestressed SFRC beam were compared against the number of cycles as in Figs. 4 and 5 respectively . The beam without fibres showed greater deflections than that of the beam with fibers. This indicates that the beam without fiber may have had some internal defects influencing either the strength of the concrete or level of prestress. The Beams were then loaded to failure .

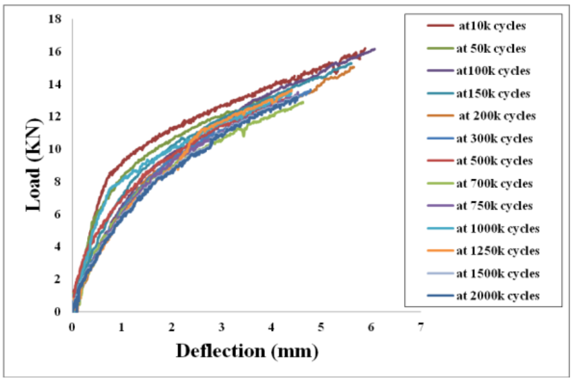

Fig 4: Load deflection curves for Plain pre-stressed concrete beam specimen.

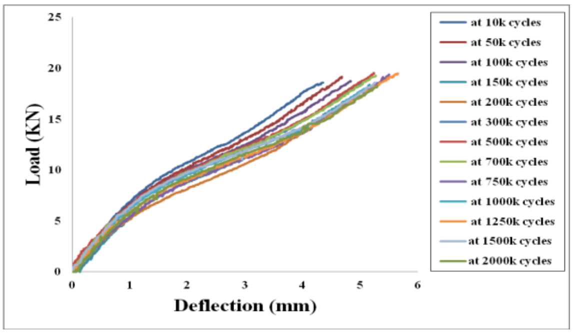

Fig 5: Load deflection curves for SFRC prestressed concrete beam specimen.

From the above figures, it can be clearly seen that the load carrying capacity of the SFRC prestressed concrete beam was more than that of the plain prestressed concrete beams. The use of steel fibres in a concrete mix was found to increase the crack resistance of the beam. This was due to the fact that the presence of fibres throughout the cross section of the beam.

Fig. 6 shows load versus deflection curve for plain prestressed concrete beam specimen under double points loading. The average load carrying capacity of the specimen was 25.45 kN. The average vertical deflection for the specimens was 62.58 mm.

Fig. 7 shows load versus deflection curve for SFRC prestressed concrete beam specimens under double points loading. The average load carrying capacity of the specimen was 31.08 kN. The average vertical deflection for the specimens was 25.65 mm.

Based on these experiments, it is clear that the addition of steel fibers results in improving fatigue life. The addition of 3% fiber by volume of concrete increased the fatigue life by 22% over that of the nonfiber reinforced specimen. It was observed that the development of the first crack for a fibre reinforced prestressed concrete beam was at higher loads than the plain prestressed concrete beam. It was also noted that deflection was satisfactory.

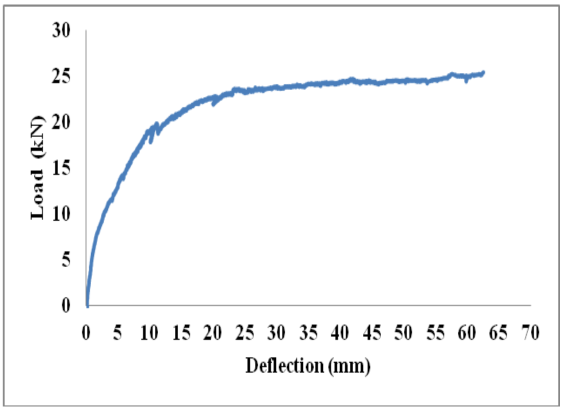

Fig 6: Static load-deflection behavior of Plain pre-stressed concrete beam up to failure.

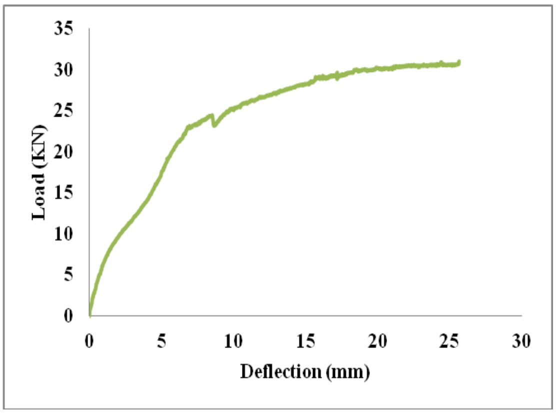

Fig 7: Static load-deflection behavior of SFRC prestressed concrete beam specimen up to failure.

The SFRC beams developed more cracks at a lower spacing than that of beam without fibers. However, the cracks in the beams without fiber tended to be evenly distributed along the length of the beams, whereas the SFRC beams experienced much closer crack spacing within the constant moment zone compared to the region outside of the constant moment zone as shown in Figs. 8 and 9.

This was due to the fact that the presence of fibres throughout the cross section of the beam.

Fig 8: Crack in prestressed plain concrete.

Fig 9: Crack in prestressed SFRC.

IV. CONCLUSIONS

The behaviour of prestressed SFRC beam with prestressed conventional reinforcement subjected to fatigue loading has been investigated. The experimental results for prestressed SFRC beam and the prestressed conventional reinforced concrete beam were compared to study the influence of fibers on the behaviour of structures under cyclic loads. The results are summarized as follows:

1. Load carrying capacity of prestressed steel fibre reinforced concrete beam specimen was more than the plain prestressed concrete beam specimen by approximately 22%.

2. The prestressed SFRC beam had lower deflection and smaller crack width over the full period of cyclic loading compared to that of the control specimen.

2. The use of steel fibres in a prestressed concrete mix was found to increase the crack resistance of the beam.

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