BEHAVIOUR OF TWO SPANS CONTINUOUS STEEL FIBRE REINFORCED CONCRETE BEAM UNDER MONOTONIC LOADING

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Thesis submitted in fulfilment of the requirements
for the award of the degree of
B.Eng (Hons.) Civil Engineering

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JUNE 2014

ABSTRACT

The experimental work presented herein is aimed at studying the effect of steel fibres on the behaviour of reinforced concrete (RC) structures designed accordance with Eurocode 2. An attempt has been made to investigate the potential use of steel fibres can result in a significant reduction in conventional shear reinforcement and satisfied the requirement of current codes for strength and ductility. In this respect, hooked end steel fibres with aspect ratio of 80 were used. Three different dosages of steel fibres in the concrete mix was based on the volume fraction of 0, 1 and 2% (0, 82, 164 kg/m^3). In this particular case, additional reduction of the conventional shear reinforcement was carried out by spacing increases (SI) of the stirrups by 50% to see whether the loss of shear strength can be compensated by addition of steel fibre. Concrete compression and flexural tests were conducted for studying the compressive strength, load-carrying capacity, ductility and energy absorption. In order to determine its mechanical properties, 27 cubes of all sides equal to 100 mm and 6 beams of dimension 200x200x3000 mm were casted. All cubes specimens was tested until failure in compression machine and found out that the compressive strength of steel fibre reinforced concrete (SFRC) is not influenced by the steel fibre contribution. However, in the flexural test of beam specimens under monotonic loading; the results indicate steel fibre highly enhanced the flexural strength of SFRC beam. Conclusively, the results revealed that steel fibres give insignificant effect to the compressive strength but highly contribute to strength enhancement of SFRC flexural behaviour. Inclusion of steel fibres allowed for a reduction of conventional shear reinforcement without compromising the ductility and load-carrying capacity. This effect has extended the mode of failure of the beam changed from brittle to a more ductile manner as the amount of steel fibres was increased in the concrete mix.

ABSTRAK

Kerja-kerja eksperimen yang dibentangkan di sini adalah bertujuan untuk mengkaji kesan gentian keluli pada kelakuan konkrit bertetulang (RC) struktur direka dengan mengikut Eurocode 2. Satu percubaan telah dibuat untuk menyiasat potensi penggunaan gentian keluli boleh menyebabkan pengurangan yang ketara dalam tetulang ricih konvensional dan mematuhi kehendak kod semasa untuk kekuatan dan kemuluran. Dalam hal ini, gentian keluli cangkuk akhir dengan nisbah aspek 80 telah digunakan. Tiga dos gentian keluli yang berbeza di dalam campuran konkrit adalah berdasarkan pecahan isipadu 0, 1 dan 2% (0, 82, 164 kg/m^3). Dalam kes ini, pengurangan tambahan tetulang ricih konvensional telah dijalankan oleh kenaikan jarak (SI) daripada stirrups sebanyak 50% untuk melihat sama ada kehilangan kekuatan ricih boleh dipampas dengan penambahan gentian keluli. Ujian mampatan dan lenturan konkrit telah dijalankan untuk mengkaji kekuatan mampatan, keupayaan menanggung beban, kemuluran dan penyerapan tenaga. Untuk menentukan sifat-sifat mekanikal, 27 kiub semua sisi yang bersamaan dengan 100 mm dan 6 rasuk dimensi 200x200x3000 mm telah dibaringkan. Semua kiub spesimen diuji sehingga gagal dalam mesin mampatan dan mendapati bahawa kekuatan mampatan gentian keluli konkrit bertetulang (SFRC) tidak dipengaruhi oleh sumbangan gentian keluli. Walau bagaimanapun, dalam ujian lenturan spesimen rasuk di bawah pembebanan ekanada; keputusan menunjukkan gentian keluli sangat dipertingkatkan kekuatan lenturan rasuk SFRC. Konklusif, keputusan menunjukkan bahawa gentian keluli memberi kesan tidak signifikan kepada kekuatan mampatan tetapi sangat menyumbang kepada peningkatan kekuatan kelakuan lenturan SFRC. Penambahan gentian keluli membenarkan untuk pengurangan tetulang ricih konvensional tanpa mengabaikan kemuluran dan keupayaan menanggung beban. Kesan ini telah melanjutkan mod kegagalan rasuk berubah dari rapuh kepada yang lebih mulur kerana jumlah gentian keluli telah meningkat di dalam campuran konkrit.

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%	Percent
mm	Millimetre
MPa	Megapascal
±	Plus-Minus
m^3	Cubic metre
kg/m^3	kilogram per cubic metre
kg	kilogram
®	Registered
N/mm^2	Newton per square millimeter
™	Trade mark
V_f	Volume fraction
P	Transverse point load
kN	Kilonewton
P_y	Load at yield
P_{max}	Maximum load
P_u	Load at failure
δ_{Pmax}	Deflection at maximum load
δ_u	Deflection at load at failure
δ_y	Deflection at load at yield
μ	Ductility
F_{crack}	First crack load
P_{maxo}	Maximum load in the control beam
P_{yo}	Load at yield in the control beam
μ_o	Ductility in the control beam
E_a	Energy absorption
E_{ao}	Energy absorption in the control beam

LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British Standard
CEM	Certified Energy Manager
e.g.	for example
EN	European Standards
etc	et cetera
IBS	Industrialised Building Systems
i.e.	that is
LVDT	Linear Variable Differential Transformer
MMD	Malaysian Meteorological Department
MS	Malaysian Standards
RC	Reinforced concrete
SCC	Self-consolidating concrete
SFRC	Steel fibre reinforced concrete
SI	Spacing increases
UK	United Kingdom
USA	United States of America

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Concrete is a major and most versatile building construction material that has been widely used in construction. It can be cast in any shape from rectangular beam or column to cylindrical power plant. The advantage of concrete are well common to high compressive strength and low maintenance which have long service life as compare to other construction material (i.e. timber and steel). However this plain concrete material is a quasi-brittle material (poor tensile strength) and easily cracked even small stress induce on it owing to its inherent weakness in resisting external forces (Z. Wang, Yang, & Wang, 2011). The disadvantage of concrete is notified since ancient years ago and fibre-reinforced materials started with straw fibres reinforced in mud bricks and horsehair in mortar (Syed Mohsin, 2012). The application of asbestos fibre cement in 1900s were widely used in the United Kingdom until the late 1960s when discovery of health dangers associated with asbestos became more widely known ("Uses of Asbestos," n.d.). In the 1960s, many alternative fibres such as steel, glass, and synthetic fibres are used as new initiative for asbestos fibre replacement in fibre-reinforced concrete (Syed Mohsin, 2012). Research into new fibre-reinforced concrete continues to this day. The application of steel fibre reinforced concrete as structural applications have become popular in the UK, the USA and elsewhere the world (Lankard & Swamy, 1974). More recently, it has been used towards greater development of IBS components, such as, steel fibre wall panel (Rahman, Hamzah, & Wong, n.d.).

Fibers such as steel fibres, glass fibres, carbon fibres, plastic fibres (i.e. polypropylene, graphite etc), and natural fibres (i.e. hemp, kenaf etc) are popular to be found in the market (Syed Mohsin, 2012). Amongst these various types, steel fibres are widely used in the reinforced concrete structures (Lankard & Swamy, 1974). The positive contribution to resist crack propagation and energy absorption capacity is favour in the uses of structural element (Tantary, Akhil, & Prasad, 2012; Z.-L. Wang, Liu, & Shen, 2008). Furthermore, the inclusion of discrete discontinuous fibres in concrete has the advantages that significantly improves the mechanical characteristics such as flexural strength, tensile splitting strength, impact resistance, toughness and ductility (K. S. Kim, Lee, Hwang, & Kuchma, 2012). In this present research will focus on the behaviour of steel fibres out of other types are outside the scope of this study.

Performance of steel fibre reinforced concrete is influenced by several factors such as shape, fibre content and aspect ratio (Khaloo & Afshari, 2005; Robins, Austin, & Jones, 2002; Sharma, 1986; Trottier & Banthia, 1994). The combination of these factors will contribute to the bonding between the steel fibres and the concrete. Fibres with deformed shapes and/or hooked ends usually provide better bonding with concrete than the straight ones (Syed Mohsin, 2012). Thus, the focus in the present research is the hooked end fibers.

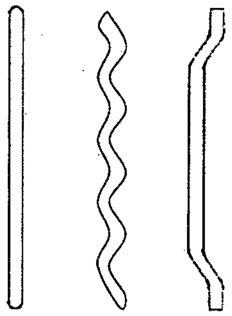

Figure 1.1: Examples of the shapes available for steel fibres

Source: K. S. Kim et al. (2012)

Recent investigations of Steel Fibre Reinforced Concrete (SFRC) such as SFRC beams under cyclic loads (Abbas, Mohsin, & Cotsovos, 2012; Kotsovos, Zeris, & Kotsovos, 2007), behaviour of SFRC under reversed cyclic loading (Hameed, Duprat, Turatsinze, Sellier, & Siddiqi, 2011), and behaviour of SFRC beams with steel fibres under flexural loading (Shukla, 2011) are mainly on simply supported beam and are subjected to cyclic loading. However, limited research done on the two spans continuous steel fibre reinforced concrete beam under monotonic loading.

According to W. Kim, 2011 there are three potential solutions to steel congestion in reinforced concrete structures which are reinforced concrete was mixed with steel fibres, the use of self-consolidating concrete (SCC), and by the use of headed bars instead of traditional hooked bars. The first and third approach is emerging as a research topic of special interest in the American Concrete Institute (ACI). Previous experimental research work (i.e.W. Kim, 2011; Lim & Oh, 1999) has demonstrated that steel fibres are capable of reducing the amount of shear stirrups yet satisfied the requirement of current codes for ductility. In this research, evaluating in the reinforced concrete when steel fibres added into the concrete mixes was used.

1.2 PROBLEM STATEMENT

Tensile strength of plain concrete is typically 8% to 15% of its compressive strength. This properties cause the concrete deteriorates rapidly and loses it service load ability soon as the first crack appear. Brittleness and lack of post-peak resistance of concrete will causes structure collapse instantaneously because in Malaysia, least consideration is given on seismic activity during structural design. According to Malaysian Meteorological Department (MMD) stated that Malaysia is close to the most two seismically active plate boundaries and thus the major earthquakes can be felt in Malay Peninsula (i.e. Bukit Tinggi, Jerantut) and East Malaysia. The increasing number of reports on the tremors felt in Malaysia after Indonesia and the Philippines hit by strong earthquakes in the past few years ("Moderate earthquake 'can happen anytime' in Malaysia," 2013). The treat of an earthquake in Malaysia cannot be ignored and due to that issues and the impact of frequent natural disaster (i.e. Tsunami and typhoon etc). The need for higher load carrying properties or even seismic design consideration in future reinforced concrete design has become more attention by the engineers.

Fibres are widely used to enhance the performance of concrete to accommodate deformations. This is exceptionally useful in seismic situations. It is very common that the conventional and seismic reinforced concrete design with the constraints of size of structural members; shear reinforcement required usually lead to congestion of shear links. In order to reduce the steel congestion while maintaining the integrity of the concrete structure, one of the potential alternatives recommended by W. Kim, (2011) is to add steel fibres into concrete mix. Investigation carried out by Lim & Oh, 1999 has conclude that the addition of fibre can reduce the amount of shear links required. Furthermore, combination of fibres and stirrups will enhance properties which may meet strength and ductility requirement. The investigations indicated structural benefits to applying steel fibres as part of the shear reinforcement. This indicates potential for reducing the steel congestion, especially in the joint area of reinforced concrete frames.

Plenty research has been conducted so far are focused on Steel Fibre Reinforced Concrete (SFRC) simply supported beams (e.g. Behbahani, Nematollahi, Sam, & Lai, 2012; Gustafsson & Noghabai, 1999; Lim & Oh, 1999; Shukla, 2011) subjected to monotonic loading and cyclic loading (e.g. Abbas et al., 2012; Hameed et al., 2011). There is limited research on the behaviour of two spans continuous steel fibre reinforced concrete beam under both monotonic and cyclic loading (Kotsovos et al., 2007). Based on the information discussed above with regards to steel fibres properties and their potential to enhance the structural response of the reinforced concrete structures, it is crucial and beneficial to investigate further and understand the behaviour of steel fibre reinforced concrete especially on two spans continuous SFRC beam under monotonic loading conditions by adding two various quantities (1% & 2%) of steel fibres. Furthermore, limited works have been carried out to examine any prospective improvement in reducing the congestion of transverse reinforcement (usually provided for shear and confinement purposes) with the introduction of steel fibres. Hence, different spacing regime (full shear reinforcement and reduce shear reinforcement) on stirrups provided is also the interest of this research to seek the inherent of steel fibres as part of the shear reinforcement and how it can complement conventional shear reinforcement arrangement. This will results in conclusions and recommendations to help minimize steel congestion.

1.3 AIM & OBJECTIVE

The main aim of this research is to investigate the behaviour of two spans continuous steel fibre reinforced concrete beam in critical stage (two not equally spans with consideration of dead and live load) under monotonic loading.

- To investigate experimentally the behaviour of two spans continuous reinforced concrete beam once steel fibres are added into the concrete matrix.
- To study the potential of steel fibre as part of shear reinforcement; especially once the spacing of stirrups is relaxed (the spacing of stirrups is increase by 50%).

1.4 SCOPE OF RESEARCH

1. Only hooked-end steel fibres are considered, with the fibres properties considered are explained in the respective work.
2. The reinforced concrete beams covered in the case studies are indeterminate two spans continuous beams. Each specimen will be molded into square cross-section of 200 mm side, with a large span of 1800 mm and a small span of 1200 mm.
3. In the experimental work, two parameters are considered for the parametric study, namely steel fibre volume fraction (i.e. ratio between volume of fibres and volume of concrete) and amount of conventional shear reinforcement. Three volume fractions are adopted to represent the fibre dosages, namely: 0%, 1% and 2%. The conventional shear reinforcement is also reduced by increasing the stirrups spacing by 50%.
4. Two control beams (without fibres) and four beams containing fibres contents of 1% to 2% will be investigated.
5. Three beams from each type of beam will undergo full shear reinforcement whereas another three beams from each type will undergo reduce shear reinforcement.
6. Large span of 1800 mm of the beam will be tested in 3 points test during age of 28 days.

7. For compressive strength test, 9 control concrete cubes (without fibres) and 18 steel fibre concrete cubes are moulded in 100 x 100 x 100 mm will be tested in compression machine at age 3, 7 and 28 days.

1.5 RESEARCH SIGNIFICANCE

It is clearly understood from the literature review that the behaviour of a beam is affected by the properties of core concrete. Ductility is concerned by engineers in the reinforced concrete frame design. This is generally accomplished by providing closely spaced of stirrups (shear reinforcement), but this normally causes difficulties in placing concrete of such densely reinforced section and resulting bad concreting problem (honeycomb). In order to resolve the issues involving steel congestion (closely spaced stirrups), low tensile characteristic of concrete has to be improved, which increases the ductility of the core concrete. In this respect, steel fibre possesses excellent tensile strength, modulus of elasticity, stiffness modulus and mechanical deformations will be added to the concrete matrix of plain conventional concrete. The special interest of the present research is to investigate the behaviour of two spans continuous reinforced concrete beams containing steel fibre subjected to monotonic loading. This will provide the information of structural behaviour of indeterminate SFRC beam in the research groups of steel fibre. Furthermore, this research would heighten the latent mechanical properties of steel fibre such as compensate the loss of shear strength, behaviour considering the steel fibre dosages, and how it can complement conventional shear reinforcement arrangements.

1.6 EXPECTED OUTCOME

Once steel fibres are added into the concrete mix. It is expected that:

1. The structural behaviour such as strength and ductility of reinforced concrete beam will become better.
2. Incorporation of discrete discontinuous steel fibre will also reduce the crack width and propagation of crack in the beam.

3. The two spans continuous steel fibre reinforced concrete beam will fail in flexural instead of shear and there is no significant increase in compressive strength when steel fibres are added.
4. The potential use of steel fibres to replace the stirrups either completely or partially.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Reinforced concrete (RC) is a major building materials and is widely used in many types of engineering structures due to its strength, stiffness, as well as economic in term of cost (Altun, Haktanir, & Ari, 2007; Kwak & Filippou, 1990). Ductility is main concern for concrete because of its low tensile strength and natural brittle character. One of the approach is by adding steel reinforcement (reinforcing bar and steel fibres), which provide tensile in the tensile zone of the concrete and also offers confinement to the concrete working in compression (Syed Mohsin, 2012). There are numerous fibre types available for commercial use such as steel, glass, synthetic materials (e.g. polypropylene, carbon, nylon) and natural fibres (Sukontasukkul, 2004).

Fibres are used to enhance the properties such as shrinkage, toughness, and the energy absorption capacity and more (Altun et al., 2007; Johnston, 1994). In order to achieve higher tensile and flexural strength, it is important to reduce the brittleness of plain concrete as well as crack control or closure mechanism thus changing the failure mode to one that includes post-cracking ductility (Hannant, 1978). It is important to ensure the bonding between the fibres and the matrix, therefore various sizes and shapes (e.g. deformed) to provide this anchorage effect (Syed Mohsin, 2012). According to Hannant, 1978, the maximum particle size in fibre-reinforced concrete is restricted to 20 mm to ensure that sufficient bonding is accomplished. In addition, the post-cracking behaviour can be affected by the number of fibres across a specific crack, effectiveness of fibre orientation, bond strength and the resistance to fibre pull-out.

Steel fibres are increasingly being used in RC structures in Malaysia. Research and development work on SFRC in Malaysia has been used in the construction of on-ground floor slab and slab-on-piles applications for industrial floors, concrete pavement and road, shipyard, airport hangar and residential houses. Other than that, steel fibres have been applied in blast furnances, tunnel linings, slope stabilisations, shotcreting works (e.g. slab toppings, composite floors, and precast floor slab) and other precast products (Rahman et al., n.d.). The example of projects in Malaysia in which steel fibres has been applied are Sepang Low Cost Carrier Terminal, Kuala Lumpur Penchala Tunnel, Kuala Lumpur SMART project and CIQ Johor Bahru ("Stahlcon Steel Fibre Technical Pamphlets," 2007).

2.2 OVERVIEW OF FIBRE

There are various types of fibres available in the market nowadays. Fibres can be obtained by various shape and sizes which produced from steel, plastic, glass, and also natural materials such as hemp and kenaf. However, for most structural and non-structural purposes, steel fibre is the most commonly used of all the fibres. There are some of the shapes available for steel fibres (e.g. straight, hooked, paddled, crimped, deformed, and irregular). Plain shape and hooked-end steel fibres are commonly used in experimental investigations (e.g. Dinh, Parra-Montesinos, & Wight, 2010; Hameed et al., 2011; Kotsovos et al., 2007). Furthermore, many researcher (Banthia & Trottier, 1994; Burakiewicz, 1978; Soroushin & Bayasi, 1991) found out that the experiments results have shown ameliorate effects of pullout resistance by using hooked-end fibre than the straight fibre.

2.3 STEEL FIBRE REINFORCED CONCRETE (SFRC)

The principal function of fibre is to improve the post-cracking behaviour of concrete which is to resist the formation and growth of cracks (Lim & Oh, 1999). Inclusion of discrete discontinuous fibres in reinforced concrete is much tougher and more resistant to impact than plain concrete. Brittle matrix of concrete fails immediately after the formation of first crack. Addition of ductile fibres can improve several properties of concrete (e.g. strength, stiffness etc) into a high ductile structural member

(Hameed et al., 2011). The presence of fibres can reduce the strain magnitude and arrest the cracks (Daniel, Loukili, & Lamirault, 2000)

2.4 CRACKS MECHANISM IN SFRC

Steel fibre reinforced concrete, the shear resisting mechanisms are mainly contributed by fibres in the beam. This will be slightly different than in normal slender reinforced concrete beams without stirrup reinforcement which attributed to contributions from the beam compression zone, aggregate interlock, and dowel action. Steel fibres play a dual role in shear resistance. First, they transfer tension across diagonal cracks. Second, by controlling the opening of diagonal cracks, steel fibres allow additional shear to be transferred through aggregate interlock and, to some extent, increased dowel action. Fibres and aggregate interlock both are relative contribution to shear strength before the beam is loaded and diagonal cracks widen. After starting diagonal cracking, a considerable amount of shear resistance is expected from both fibres and aggregate interlock. Withal, as diagonal (or flexural-shear) cracks widen, particularly as a result of flexural yielding, shear resisted by aggregate interlock will tend to break down at a faster rate compared to the contribution from fibre reinforcement and causes shear resistance rely more on fibre than aggregate interlock, particularly for beam with relatively small total size. Thus, during flexural yielding, the fibre contribution will likely control the amount of shear resistance by stirrups to shear failure.

2.5 PREVIOUS RESEARCH ON SFRC

In the research by Lim & Oh, 1999 on the behaviour of reinforced concrete beams containing steel fibres subjected predominantly to shear with the major variable of the amount of steel fibres and the volume of shear stirrups, found out that the addition of steel fibres can enhance the tensile properties and more resistant to cracking. Strength such as compressive, flexural, and tensile splitting had improved. The mode of failure changed from shear to flexure when the amount of steel fibres used exceeds about 1% this meaning the addition of fibre reinforcement will greatly increase shear capacity. The use of fibre reinforcement can reduce the amount of stirrups and may satisfy the strength and ductility requirement.

From the two point monotonic loading tests on reinforced concrete beams by Shukla, 2011, SFRC beams showed significance increase in first crack load. The performance of structures at service load also increase in SFRC beams. From the finding, it is evident that SFRC beams show better stiffness characteristics than reinforced concrete beams.

Further investigation on the effect of various type and combinations of steel fibres (e.g. volume fractions of steel fibres, length, geometrical dimensions etc) studied by Gustafsson & Noghabai, 1999 had drawn conclusion that by adding small amount (1 or less) of steel fibres can possible reach shear capacities of the same order as in the case of conventional stirrups, at least for small beams with an effective depth of about 200 mm. With a mix of short, straight fibres and hooked end long fibres will provide the best contribution to the shear resistance of the beams. Larger amounts of steel fibres are needed in a structure that has higher brittleness in order to be able to carry excessive load.

The effect of metallic fibre addition on the energy dissipation capacity of the reinforced concrete beam is investigated by Hameed et al., 2011 draw the following conclusions; metallic fibres in reinforced concrete beams induces an important reduction in flexural crack width at a given amplitude level and substantial reduction in spalling of concrete in the presence of metallic fibres.

Above investigation is conducted on simply supported beam whereas the research conducted by Kotsovos et al., 2007 is on the indeterminate beam. In the research on the effect of steel fibres on the earthquake-resistant design of reinforced concrete structures has conclude that specimens with steel fibres satisfied the requirement of current codes for strength and ductility for concrete strength up to 60 Mpa. For higher values of concrete strength, although there is great improvement in performance as compared to specimens without fibres, yet the code requirements for ductility does not meet.

To summaries, addition of steel fibres will normally increase the performance of concrete from strength to ductility and with the combination of stirrups, the reduction of shear capacity will compensate by fibre reinforcement. Steel fibres as crack resistant in concrete will help to reduce the crack width and even bridge the cracking. The use of hooked end steel fibre will give better bonding between fibre and concrete. This will reduce the chance of failure of concrete by the pull-out effect. To conclude, reinforced concrete with the addition of steel fibres will satisfy the requirement of current codes with reducing the amount of the stirrup.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 PREPARATION OF CONCRETE INGREDIENTS

Details of the constituent materials made up of concrete will be described in this chapter as well as the method of preparation.

Steel fibre reinforced concrete is design by using trial mix design method. This method is used to determine the appropriate workable mix proportions. In accordance to British method of concrete mix, the compressive strength of hardened concrete is generally considered to be an index of its other properties and the slump is controlled at the range of 75±25mm.

Table 3.1: Concrete mix details for 1m^3 of concrete mix

Material	Quantities
Cement (kg/m^3)	450
Sand (kg/m^3)	765
Crushed stone (kg/m^3)	935
Superplasticizer (kg/m^3)	2.25
Steel fibres, V_f (%)	0% - 2%
Water (kg/m^3)	225