FLEXURAL BEHAVIOR OF PRECAST CONCRETE SLAB WITH STEEL FIBRE CONCRETE TOPPING

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To my beloved family

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ABSTRACT

Considerable interest has been developed in using fibres is concrete to increase the load-carrying capacity of structures in service. Fibre reduces brittleness of concrete and improves its engineering properties such as tensile, flexural, impact, fatigue, load bearing capacity after cracking and toughness. Among fibres, steel fibre is one of the most popular and widely used fibres in both research and practice. Steel fibre-reinforced concrete (SFRC) has been used increasingly in recent years and has applied to various structural components. It is also known that using 0.5 – 2.5 % fibre in concrete mix can significantly improve the concrete properties. In recent years, it has been used as a strengthening technique for concrete slabs. Cement-base bonded overlay technique consists of applying a thin layer of SFRC onto the existing slab. Beneficial effect of fibre reinforcement on the durability of cement-base bonded overlay has been amply demonstrated by previous researchers. The objective of this research is investigation on flexural behavior of precast concrete slab with steel fibre concrete topping. The parameter investigated includes steel fibre volume fraction and surface condition between old and new concrete. A series of 108 specimens (cube, cylinder and prism), without and with three different steel fibre volumes were investigated by ratio of 0.7%, 1.0% and 1.5% to determine the optimum percentage volume of steel fibre in application to reinforced concrete topping. To reinforce the concrete overlay, hooked-end steel fibres was used; length of 30 mm and diameter of 0.75 mm. These slabs have three different surface textures between the substrate and concrete topping which include smooth as-cast and roughened in both longitudinal and transverse direction. The results show good reliability on using SRFC as concrete topping replacing the conventional construction method. The highest bond strength was achieved with roughening the top substrate in transverse direction which can sustain 2.5 times more moment compared with the calculated values.

ABSTRAK

Penggunaan gentian di dalam konkrit untuk meningkatkan kapasiti dan keupayaan beban servis di dalam sesuatu struktur telah menarik minat penyelidikan pada masa kini. Gentian mengurangkan kerapuhan dalam konkrit dan meningkatkan keupayaan tegangan, lenturan, hentaman, kelesuan, kapasiti galas selepas keretakan dan kekerasan. Gentian keluli merupakan bahan gentian yang paling popular digunakan sama ada di dalam penyelidikan mahupun praktikal. Gentian keluli konkrit bertetulang (SFRC) menunjukkan peningkatan dalam penggunaannya pada masa kini dan telah banyak diaplikasikan untuk pelbagai struktur komponen. Ianya juga telah diketahui bahawa kandungan gentian di antara 0.5 – 2.5% di dalam sesuatu bancuhan konkrit berupaya meningkatkan ciri konkrit. Sejak kebelakangan ini, ianya telah mula digunakan dalam teknik penguatan papak konkrit. Teknik dasar-simen pengikat penutup merupakan satu kaedah di mana satu lapisan nipis SFRC dibancuh di atas papak sedia ada. Kelebihan tetulang gentian dari segi ketahanlasakan ke atas dasar-simen pengikat penutup telah dibuktikan oleh penyelidik yang lepas. Objektif utama kajian ini adalah untuk mengkaji kelakuan lenturan papak konkrit pratuang dengan konkrit penutup gentian keluli. Parameter kajian termasuklah nisbah isipadu gentian keluli dan keadaan permukaan di antara konkrit baru dan lama. Sebanyak 108 spesimen (kiub, silinder dan rasuk), tanpa dan dengan tiga isipadu gentian keluli dikaji dengan nisbah 0.7%, 1.0% dan 1.5% untuk menentukan peratusan isipadu optimum gentian keluli bagi aplikasi kepada penutup konkrit bertetulang. Untuk tujuan ini, gentian keluli berbentuk *hooked-end* telah digunakan; panjang 30 mm dan diameter 0.75 mm. Papak yang dikaji disediakan dengan tiga permukaan yang berbeza di antara substart dan penutup konkrit iaitu licin dan kasar dalam arah pemanjangan dan pelebaran. Hasil kajian menunjukkan keupayaan SFRC sebagai penutup konkrit menggantikan kaedah konvensional dalam pembinaan. Kekuatan ikatan yang paling baik adalah dengan mengasarkan permukaan atas substrat dalam arah kelebaran, di mana ianya boleh menanggung momen lenturan 2.5 kali lebih tinggi daripada nilai teori.

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CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is a widely used construction material which exhibit brittle behavior and has a lot of application. In recent years, many researchers have done various methods such as using larger steel bars to increase the load carrying capacity of concrete members. These methods are used in heavily loaded structures, lighter ones require finer reinforcement which can be best provided by fibres. In the last few decades, increasing in using different kind of fibre has increased among researchers.

Fibres considerably reduce brittleness of concrete and improve its engineering properties. Fibre reinforced concrete is made by two components, matrix and fibre. The matrix material is brittle and the choice of it for using with steel fibre concrete (SFC) depends on the intended use of material. The fibre component is either a ductile, high modulus material such as steel and asbestos, or low modulus material such as polypropylene, polyethylene and nylon. The yield and failure strain of all fibre are greater than the yield and failure strain of the matrix material.

Steel fibre is one of the most popular and widely used fibres in both research and practice. In 1963, Romualdi and Batson reported significant improvement in concrete properties through the use of randomly distributed steel fibre. Steel fibre-reinforced concrete (SFRC) has been used increasingly in recent years. It is used in various applications such as mine and tunnel linings, slabs and floors, rock slope stabilization, repair mortars, shell domes, dam construction, composite metal deck, repair marine structure, fire protection coating and in conventional RC frames. SFRC considerably increases energy absorption capacity (toughness), reduce cracking and improve durability of plain concrete.

There are many factors that affect on mechanical properties of SFRC including specimen geometry, curing time, water/cement ratio (w/c), types of cement and supplementary cementitious material, steel fibre geometry, aspect ratio and volume fraction. Round, square and rectangular cross section fibres are different shapes of steel fibres. There is also another fibre shape in spring form and with circular or rectangular cross section which there is not many documents about it.

Normally, steel fibres are stainless with low carbon, 0.254 to 0.635 mm in diameter and 19.5 to 50.8 mm in length. Many documents have shown that a range of 1.0 to 2.5% steel fibre volume dosage in concrete is more suitable. Smaller dosage of less than 1.0% does not have too much effect. Dosage beyond 2.5% also has negative effect and reduces compressive strength due to difficulties in providing uniform fibre distribution. Easy workability is another reason for dosage restriction to 2.5% because upper than this amount make it hard to spread the concrete.

In general, using of fibres in concrete considerably improves many of the mechanical properties of concrete such as tensile, flexural, impact resistance, fatigue, abrasion strength, deformation capability, load bearing capacity after cracking and toughness properties. Steel fibres do not have considerably influence in flexural characteristics of concrete prior to cracking. Presence of steel fibre in concrete does not much effect on the ultimate strength of concrete. The main effect of steel fibre is on energy absorption capacity (toughness) and prevention of crack propagation in concrete. Steel fibre increases energy absorption capacity which is defined by the area under load-deflection curve. It is obvious that pulling out the fibre from concrete matrix require more energy, therefore SFRC toughness and resistance to dynamic loading increase.

When tension stress occurs on the bottom of specimen due to bending, the first crack develops. The presence of fibre in concrete helps to restrain early crack growth and transfer load to the uncracked parts, thus increases durability of concrete and withstand higher tensile loads at failure.

Furthermore, presence of steel fibre in concrete does not much effect on the ultimate strength of concrete. Slight influence on the ultimate strength is the result of changes in compressive strength of concrete caused by the addition of fibre. Published data about the effect of steel fibre on the compressive strength is few. Steel fibres also do not have considerably influence on flexural characteristics of concrete prior to cracking.

Today's, one of the interesting aspect of using fibres among researchers is for repair and strengthening of existing structures using SFRC topping in structural elements. This technique is known as cement-base bonded overlay. It is not too far that beneficial effect of steel fibre reinforcement on the durability of cement-base bonded overlay has been amply demonstrated. Cement-base bonded overlay is a frequently used technique for improving the mechanical capacity of an element by increasing its thickness. This technique can be used in different types of precast concrete forming system including slabs, walls, beams, columns. At first, normal reinforced concrete topping is widely used, but documents show that it is more rational to use fibre reinforced concrete, even if it is more expensive. The thickness of in-situ concrete topping is variable between 40 to 100 mm depending to length of fibre used. The aim of this research is using cement-base bonded overlay method on precast slab to enhance the structural performance of the floor by producing a composite structure.

1.2 Problem Statement

In this technique, the substrate and overlay behaves as a composite member and are expected to work monolithically. In this case, substrate is precast unit and overlay is in situ concrete topping. When the member is bent, the substrate and overlay will tend to move against to each other as shown in Figure 1.1. Without good adhesion between those two layers, the composite member will collapse early due to failure at the interface. Therefore, efficiency of cement-base bonded overlay depends on the bond characteristic between the precast unit and added concrete

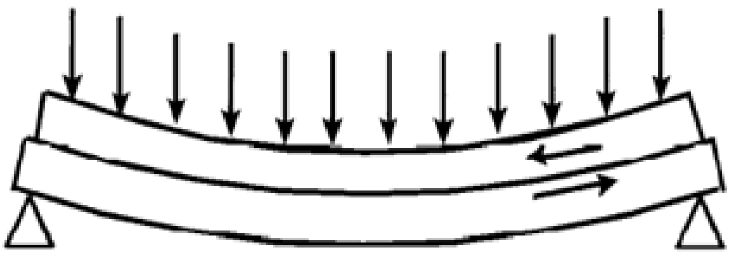

Figure 1.1: Interface Shear Stress of Composite Member

As a result of previous experiments, cracking and debonding play an important role in performance of overlay. Debonding becomes possible because of cracking of the overlay and because of the tendency of the overlay not follows the curvature of the substrate. Proposed debonding mechanism is shown in Figure 1.2. A crack passing through the overlay and cuts the continuity of stress transmission within the volume of the overlay. A reinforcement of the overlay enables force transmission across the crack and decreases the intensity of the mechanical discontinuity. Consequently, it decreases the built-in peak stresses at the interface.

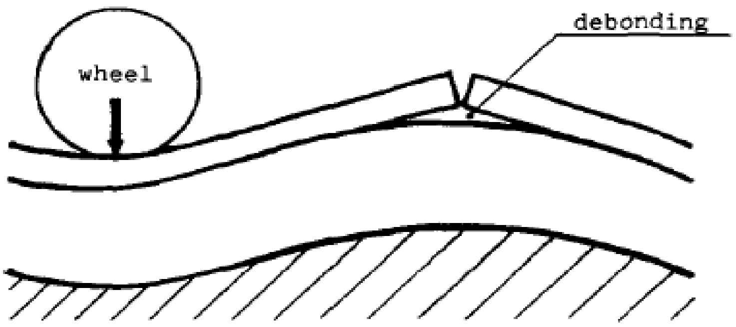

Figure 1.2: Proposed Debonding Mechanism

The horizontal shear between the two layers can be resisted by the shear capacity of the interface. Using shear key, adhesive material and roughen the interface are different methods to increase shear capacity of the interface and transferring the horizontal shear. Shear key is in the form of a loop which projects across the shear interface. Using of mechanical shear key will significantly improve the bending strength and stiffness. Figure 1.3 shows the position of reinforced shear key in precast members.

Figure 1.3: Shear Key in Precast Member

Nevertheless, reliance has to be on the contact surface between the two layers. Roughen the interface which has used in this research is the most economical method to increase shear capacity of the interface.

Different in volume changes between substrate and overlay also can affect the performance of the composite member. These failure mechanisms are largely results of. Overlay volume changes are caused at very early ages due to the effects of hydration heat development and possible plastic shrinkage. At later ages it is a major concern for the performance of the composite member. Environmental temperature changes may add to the problem when substrate and overlay have different thermal properties or when the overlay experiences a significant temperature gradient through its depth. Therefore, the overlay is subjected to shrinkage and thermal movements, while the substrate deformations are usually minor or negligible.

Also, in cement-base bonded overlay method, failure can occur at the surface concrete, at the bond interface and at the overlay or as a combination of these failures. This technique can be considered adequate if the fracture surface occurs in the concrete substrate.

The other common problem is associated with procedure of mixing fibre in matrix. In mixing process, the last step is adding the fibre. Fibres can be add by hand or mechanical dispenser to ensure good distribution and eliminate fibre balling. It is also known that the tendency of fibres to ball is reduced by decreasing in fibre length or increase its diameter.

1.3 Objectives

The objectives of this research are:

(a) To study the mechanical properties of fibre reinforced concrete

(b) To study the flexural behavior of precast slab with fibre reinforced concrete topping

(c) To study the interface slip of fibre reinforced concrete topping and precast slab

1.4 Scope of Study

The purpose of this research is adding a thin layer of SFRC to precast solid slab for increasing the flexural strength by providing a composite member. Steel fibre used to reinforce the topping is to decrease the built-in peak stresses at the interface, thus increases flexural behavior of the composite member. A total number of four precast units including one for control was prepared in this study with different roughness at the interface. Combined bending and shear test machine use to assess the performance of these specimens through the shear capacity and load-deflection relationships of the composite slabs.

The reliability of this technique is based on transferring the horizontal shear of the interface. Roughening the surface is the best method to transfer the horizontal shear when there is no shear key. The reason for surface roughening is to increase the shear capacity at the interface to resist the horizontal shear between the two layers. Different roughness surface including smooth, roughened in both longitudinal and transverse direction will test for finding the one with maximum shear strength at the surface.

1.5 Importance of Study

Nowadays, the use of precast concrete in multi-storey framed buildings is widely used. It combines the benefits of very rapid construction and high quality materials with the advantages of production line economy and quality assurance.

In precast structures, there are a number of situations where it is necessary to increase the load-carrying capacity of members. The purpose of this study is adding in-situ concrete topping to precast slab for enhancement the structural performance of the floor by producing a composite structure. For improving composite performance, decreasing the serious problems of overlay which are mainly due to cracking or debonding and explained before is necessary. By improving the composite performance, the overall construction cost and maintenance cost can be reduced. The importance of this study is knowledge enhancement for others which leads to improve slab industry and reducing the overall construction cost.

1.6 Thesis Structure

Following parts form structure of this thesis:

(a) Chapter 1 introduced the concept of precast and techniques for increasing the flexural strength capacity of precast slab
(b) Chapter 2 discussed previous research on the subject and their progress
(c) Chapter 3 describe about samples preparation and the procedure for combined bending and shear
(d) Chapter 4 discuss the experimental results
(e) Chapter 5 presents the analysis and discussion of the experimental results
(f) Chapter 6 presents the conclusions and recommendations for further investigation