Available online at www.sciencedirect.com
SCIENCE DIRECT®
Construction and Building Materials 19 (2005) 595–603
Construction and Building MATERIALS
www.elsevier.com/locate/conbuildmat

Repair and structural performance of initially cracked reinforced concrete slabs

Waleed A. Thanoon, M.S. Jaafar *, M. Razali A. Kadir, J. Noorzaei

Department of Civil Engineering, Universiti Putra Malaysia, UPM, Serdang, Selangor, 43400 Darul Ehsan, Malaysia

Received 29 November 2002; received in revised form 10 September 2004; accepted 28 January 2005
Available online 21 March 2005

Abstract

Crack is one of the most common defects observed in reinforced concrete slabs and beams. Major cracks in concrete structures may occur due to overloading, corrosion of reinforcement or differential settlement of support. To restore the structural capacity of the distressed elements, retrofitting and/or strengthening are needed. There are different techniques available for retrofitting and strengthening of different reinforced concrete structural elements reported in the literature. This paper investigates the structural behaviour of cracked reinforced concrete one-way slab, which is repaired using different techniques.

Five different techniques are used for the purpose of repair in the cracked concrete slab namely; cement grout, epoxy injection, ferrocement layer, carbon fibre strip and section enlargement. The slabs were loaded to failure stage and the structural response of each slab specimens have been predicted in terms of deflection, variation of strain in concrete and steel, collapse loads and the failure modes.

The efficiency of different repair and strengthening techniques and their effects on the structural behaviour of cracked one-way reinforced concrete slab had been analyzed. It was observed that the type of repair technique used will affect the load carrying capacity of the slab and will lead to a redistribution of the strains and hence stresses in both concrete and steel reinforcement. All repair techniques are found to be able to restore or enhance the structural capacity of cracked concrete slabs.

Keywords: Repair and strengthening; Distressed concrete slab; Ferrocement; CFRP; Epoxy injection; Grouting; Section enlargement

1. Introduction

In practice, situations arise where existing concrete structures or some of their components may, for a variety of reasons, be found to be inadequate and in need of repair and/or strengthening. The inadequacy may be due to mechanical damage, functional changes, overstress due to temperature changes, or corrosion of reinforcement. A common feature of a number of different causes of deterioration is that there is a reduction of the alkalinity of the concrete, which allows oxidation of the reinforcing steel to take place. This oxidation process leads to cracking of the concrete and possible spalling of the cover to the reinforcement.

Bridges are one of the concrete structures, which normally exhibit severe distress due to their exposure to harsh environment. Different repair techniques have been successfully developed to strengthen a given structure or part of it to restore its serviceability and strength. It is also prudent to consider durability aspect when repair or strengthening is carried out. With the advancement of new materials technology, which have superior mechanical properties and excellent resistance to electrochemical corrosion, many effective repairs and strengthening techniques have been developed. The final selection of a suitable and most effective method generally depends on simplicity, speed of application, structural performance and total cost.

Studies have shown that fibre reinforced plates (FRP) increase the strength of flexural members significantly. Carbon fibre reinforced polymer has a high strength to

* Corresponding author. Tel.: +603 89466377; fax: +603 86567129.
E-mail address: msj@eng.upm.edu.my (M.S. Jaafar).

0950-0618/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2005.01.011

weight ratio, favourable fatigue behaviour and excellent resistance to electrochemical corrosion to make it practically suited for structural application [1]. A study conducted by Alfarabi et al. [2] showed that, although the FRP increase the failure loads, most of the beams strengthened by FRP started the failure at the curtailment zones of the plates. The epoxy used to laminate the plate at the soffit of flexural members only failed at loads much higher than the required level [3]. Similar study also found that the failure modes for repaired structures may change from ductile to brittle [4]. The probability of this change depends largely on the percentage of FRP being used, the location of FRP and the presence of shear reinforcement in the existing structures.

Toong and Li [5] investigated the effect of using carbon fibre reinforced polymers (CFRP) plates to strengthen one-way spanning slab to increase the flexural capacity with particular emphasis on the cracking behaviour at working load. All the CFRP strengthened specimens exhibited large increase in load carrying capacity ranging from 60% to 140%.

Ferrocement is a type of thin composite material made of cement mortar reinforced with uniformly distributed layers of continuous, relatively small diameter wire meshes. The use of ferrocement proper in repair was first introduced by Romualdi [6] and Iron [7] in the early 1980s mainly as relining membranes for the repair of liquid retaining structures, such as pools, sewer lines, tunnels, etc. Investigation into the use of ferrocement as strengthening components for the repair and strengthening of reinforced concrete beams was reviewed by Paramasivam et al. [8]. In general, the damaged concrete and reinforcement (if also damaged) were removed and replaced with ferrocement, with or without any changes in overall dimensions of the beam. The beams were tested under static or cyclic loading [6] conditions. The strengthened beams were reported to exhibit improved cracking resistance, flexural stiffness and the ultimate loads compared to the original beams. These improvements; however, depend on the full composite action between the ferrocement layers.

Al-Kubaisy and Zamin [9] presented the flexural behaviour of reinforced concrete slabs strengthened with ferrocement tension zone cover. Twelve simply supported (500 mm^2) reinforced concrete slabs were tested under flexural load. The effect of the percentage of wire mesh reinforcement in the ferrocement layer, thickness of the ferrocement layer and the type of connection between the ferrocement layer and reinforced concrete slab on the ultimate flexural load, first crack load, crack width and spacing and load–deflection relationship were considered.

Other technical methods used for repair of reinforced concrete structures are epoxy injection and cement grouting techniques. These techniques are widely used to treat cracking problem in concrete. The procedure used is well established in the literature [10–12].

This paper presents a study on the effects of different repair techniques on the structural response of one way reinforced concrete slab. The techniques include:

(a) carbon fibre reinforced polymers (CFRP) strip;
(b) cement grout, i.e., SikaGrout214;
(c) epoxy injection, i.e., Sikadur52;
(d) ferrocement cover and;
(e) section enlargement.

These techniques had been selected for their potential to either increase the structural capacity of members or to restore the original capacity of the sections. Furthermore, this study focuses on the serviceability, strength and ductility performance for each of the repair techniques to ascertain their potential application in cracked reinforced concrete slabs.

2. Experimental procedure and repair technique

In order to investigate the effect of various repair techniques on the structural response of one way slab, a total of six full scale one-way reinforced concrete slabs having a dimension of 2.5 m long × 1.0 m wide and 0.15 m thick are cast, cured and tested. The steel reinforcement consists of five 10 mm diameter high-yield deformed bars with a characteristic strength of 460 N/mm^2. The 28-day cube compressive strength, f_{cu} of the concrete used is 30 N/mm^2. All specimens are tested under two-line load located in the middle third of the slab specimen as shown in Fig. 1. Initially, all slabs are loaded to 2/3 of their expected ultimate load capacity or after the development of cracks in the specimens (initial load ranges between 34 and 40 kN), except for the control slab, which is loaded until failure. Subsequently, the load has been released and the specimens

Fig. 1. Test set up.