FLEXURAL BEHAVIOR OF REINFORCED CONCRETE (RC) BEAMS RETROFITTED WITH STEEL PLATES UNDER SUSTAINING LOADS

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ABSTRACT

In this research, the experimental work is on strengthening the Reinforced Concrete (RC) structure by using steel plates in different configuration. Repair or strengthening the Reinforced Concrete (RC) beam had become very common in all country. The RC beams mostly repair by externally retrofit with Fibre Reinforced Polymer and plates. The flexural of the beams can be achieved by using different retrofitting materials. The crack RC beam can be strengthening after repair with FRP or plate. The FRP consist of Carbon Fibre Reinforced polymer (CFRP), Glass Fibre Reinforced Polymer (GFRP), Aramic Fibre Reinforced polymer (AFRP) and also steel plate. In this research, the steel plate was used to repair the cracked beams sample. The concrete grade of all beams is 30MPa. The size of the beams is 150mm x 250mm x2000mm. The beams are cure for 28 days by put the wet cloth on the beams and make sure the cloth is moisture to prevent dehydration. The beams were compress by Frame Testing Machine (FTM) until to get a first crack and stop the machine. The beams were taken out for repair by inject epoxy into cracking part and gun the steel plate on the beams. The steel plate with width 30mm is used. The ten pieces of steel plates were wrapped on each RC beam. There were arranging in two different sequences of U- jacket and L-jacket. The experimental results of this research can be used in the industry to strengthen the cracked beams rather than being demolish. However, further study is needed to carry out to get a better result which having higher strength of RC structure.

ABSTRAK

Dalam kajian ini, kerja-kerja eksperimen adalah menguatkan konkrit struktur dengan menggunakan plat keluli dalam konfigurasi yang berbeza. Pembaikan atau mengukuhkan konkrit bertetulang rasuk telah menjadi sangat biasa di semua negara. Konkrit bertetulang rasuk kebanyakannya penbaikan dengan luaran membalut dengan Polimer Bertetulang Gentian dan plat. Lenturan rasuk pada konkrik struktur boleh dicapai dengan menggunakan bahan-bahan pemulihan peralatan yang berbeza. RC rasuk retak boleh mengukuhkan selepas pembaikan dengan Bertetulang Gentian polimer atau plat. Bertetulang Gentian polimer terdiri daripada karbon Bertetulang Gentian polimer (CFRP), Kaca Gentian Polimer Bertetulang (GFRP), Aramic Bertetulang Gentian polimer (AFRP) dan juga plat keluli. Dalam kajian ini, plat keluli telah digunakan untuk membaiki sampel rasuk yang retak. Gred konkrit yang digunakan untuk semua rasuk adalah 30MPa. Saiz rasuk adalah 150mm x 250mm x2000mm. Rasuk adalah penawar untuk 28 hari dengan meletakkan kain basah pada rasuk dan memastikan kain basah untuk mengelakkan dehidrasi. Rasuk telah memampatkan oleh Mesin Ujian Frame (FTM) sehingga untuk mendapatkan retak pertama dan berhenti mesin. Rasuk telah dibawa keluar untuk dibaiki dengan menyuntik epoxy ke dalam bahagian retak dan pistol plat keluli pada rasuk. Plat keluli dengan lebar 30mm digunakan. Sepuluh keping pinggan keluli dibalut pada setiap rasuk RC. Terdapat mengatur dalam dua jujukan yang berbeza U-jaket dan L-jaket Keputusan eksperimen kajian ini boleh digunakan. dalam industri untuk mengukuhkan rasuk retak dan bukannya merobohkan. Walau bagaimanapun, kajian lanjut diperlukan untuk menjalankan untuk mendapatkan keputusan yang lebih baik yang mempunyai kekuatan yang lebih tinggi daripada struktur RC.

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LIST OF ABBREVIATIONS

RC	Reinforced Concrete
FRP	Fibre-Reinforced Polymer
CFRP	Carbon Fibre-Reinforced Polymer
GFRP	Glass Fibre-Reinforced Polymer
PC	Portland Cement
FTM	Frame Testing Machine

LIST OF SYMBOLS

kN	KiloNewton
mm	Milimeter
%	Percentage
MPa	Mega Pascal
GPa	Giga Pascal

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The technique of strengthening Reinforced Concrete (RC) structure by bonding with steel plates on structure surface by epoxy resin has been applied recently. There are several case studies and experimental work had been done to determine the behavior of the materials used. The knowledge between steel plate, the concrete structure and epoxy bond is important to make sure that they have interaction among their properties.

Fibre - reinforced polymer (FRP) plates and steel plates had become very famous nowadays in construction. Dr Sue had stated that FRP materials are designed for repair, maintained and replace for the structure to get the best performance for the structure. FRP plates can be classified into two types, which are carbon - fibre reinforced polymer (CFRP) and glass-fibre reinforced polymer (GFRP). Every types of FRP have their own properties.

FRP composite materials are used by United States in repairing the infrastructure and it is attractive in strengthening the reinforced concrete structure. It also have high strength to weight ratio and resistance to corrosion, low maintenance required (Kachakev, Green and Barnes 2000).

The strength of the structure which retrofits by FRP can be twice but can reach 10 times higher than mild steel. The FRP can have excellent corrosion resistance. Besides that, FRP able to make work easy and it can reduce labor cost and maintenance cost (Teng et al. 2002; Bank 2006).

The goal of the retrofit the structure is to improve the shear strength of the crack reinforced concrete beams. The different configurations of steel plates considered U-jacketing and L-jacketing.

1.2 PROBLEM STATEMENT

Nowadays, before a developer or clients construct a building, they will first consider the time, budget and environment issue and this is very important in the construction world to prevent the polluted the beautiful environment. There are some ways to strengthen the RC beams and prevent the crack on the beam.

According to Bimal and Hiroshi (2005), there is RC bridge structures constructed before are no longer considered safe due to heavy loads and increasing of the vehicles. The upgrading of design had been done in many countries around the world. At the same time, most of the bridge around the world need of replacement or strengthening. In term of cost, the replacement of the bridge is much higher than the strengthening bridge with appropriate method.

Vilnay stated that the effect of the properties of the steel and concrete and their geometrical parameters on the structural behavior of strengthening element is suitable for design and apply in the industry.

From the previous researcher, reinforced concrete beams in buildings are increasing by retrofitted by steel plates to strengthen the structure. The use of FRP plates or steel plates to retrofit the beam is inexpensive and it and be done within a short time. The price of the FRP plates is expensive than the steel plates. Therefore, in the research, the steel plates are used to test its strengtheners.

1.3 OBJECTIVES

i. To investigate the shear strength of the RC beam retrofit with steel plate in different configuration.
ii. To investigate the deflection of the RC beam retrofit with steel plate in different configuration.
iii. To investigate the crack patterns of the RC beams retrofit with steel plate in different configuration.

1.4 SCOPE OF STUDY

The scope of this project is to test the strengthening of the RC beam which wrapping by steel plate with different sequences on the beams. These experiments are conduct in concrete laboratory. The cement used is Portland cement with concrete grade 30Mpa. The reinforcement steel using in the beams is Y12 and R8.

Every experiment is doing three RC beams and wraps steel plate at different position on the beam. A beam without wrapping with steel plate is use as control beam. The size of the beams samples with size of 150mm x 250mm x 2000mm is made for testing. The duration for the curing process is 28 days and curing by tape water. The average result is taken.

In determining the shear strength, deflection and crack pattern of the RC beam, the casted beams are firstly test and compress on the Frame Testing Machine (FTM) until get the first shear crack. The compressed beams are taken out from the machine and put on the support to repair the beams. The epoxy resin is inject into the crack and left it for a days for dry and then bonded the steel plate with the beams with epoxy. The steel plates wrap at different position of the beam which are U-jacketing and L-jacketing.

1.5 SIGNIFICANCE OF THE STUDY

The Carbon Fibre Reinforced Polymer (CFRP) had become very common use in the construction repair and also strengthens the structure but in term of cost, the price of CFRP is much higher than others fibre reinforced polymer. In this research, the steel plate is used to retrofit the RC beam in different consequences. The shear strength and the deflection are determined through experiment. The results of the experiment may use to apply in the industry and replace the CFRP. Besides that, this research also investigates the properties of steel plate and its mechanism. The strengtheners of steel plate also can investigate and also comparing with steel yield. According to Hamid Mahmood, 2002, he had do the research and show that the strengtheners of FRP are four to nine times higher than the steel yield stress. From this, the FRP can be replacing with steel and it can save the cost and it's easy to install to the structure.

The purpose of the research is strengthening the cracked RC beam with steel plate in different configuration of steel plates on the beam. The strength of the repaired beams is determined and does the comparison among the beams which having different configuration of steel plates bonded on the beams.

1.6 EXPECTED OUTCOME

Based on the previous researcher had shown that the FRP can be used in strengthen and repair the structure. In this research, the steel plates are used to retrofit the RC beam with different consequences on the beams. The result of the strengthen beams is compare with the controlled beam.

The expected for the results of the RC beams which retrofit with steel plate sheets is having far higher compare to the controlled beam so that it can also use in industry to strengthen the building structure. At the same time, the cracking pattern on the retrofit beam also can be lesser than the control beam.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is describing the review of the previous researcher and previous study of RC beams strengthening in shear with steel plate. This chapter also review existing knowledge related to RC beams strengthened in shear with FRP plates. This chapter describes the materials used in experiments, reinforced concrete beams, the issues with shear strengthening RC beams with FRP and mechanism properties of steel plates wrapped beam.

2.2 MATERIALS USED TO RETROFIT EXISTING DAMAGED BEAMS

The behavior of FRP materials is linear elastic to failure. It has higher strain than steel yielding strain and it can reach four to nine times the steel yield stress of steel.

2.2.1 Fibre Reinforced Plastic (FRP) Plate

The uses of FRP plates had been used in the early of 1960s in America and France in strengthening the concrete structure by bonding FRP plates to concrete surface with epoxy resins. Carbon FRP (CFRP) and glass FRP (GFRP) plates cannot be fixed by anchoring because they may split easily due to larger tensile load. The epoxy is used to attach the FRP plates with the concrete surface.

FRP composite plates can be used as an effective means of providing additional reinforcement. The needs for the flat surface for bonding, the cost and the difficulties of achieving the bonding between concrete and composite plates sufficient used for prevent debonding from governing the failure mode.

Michael et. al. had stated that the used of composite materials for structural retrofit shows great promise. The composite materials have beneficial characteristic as non-corrosive and resistant to the chemical and having high strength to weight ratio. The bonding of the FRP composite plates to reinforced concrete beam to improve the strength and flexural stiffness. According to the previous researcher Priestly et.al., he also found that the wrapping of concrete structure with epoxy jackets to provide the additional flexural and shear strength needed to seismic regions.

2.2.2 Characteristic of Steel Plate

Michael et. al. also found that the application of steel plates bonded to concrete structure has been subjected of ongoing research since many years ago. Steel plates bonded with tension face on the concrete beams have effective in enhancing flexural stiffness and reducing deflection and controlling cracking and also increasing flexural capacity. The stress concentrations at the ends of the plates can lead to premature debonding of the plates and it employed in help alleviate the problems. This provides useful sight in methods of bonding plates to concrete.

Sheets and plates are commonly using in the construction nowadays in strengthening or rehabilitation the structure. The sheets commonly used for shear reinforcement and flexural strengthening the structure. It also has a low thickness to width ratio. The sheet also in flexibility form and it can form irregular surface geometry especially curved surfaces.

Adhikary et al. (2005) had stated that the shear strength of beam increases with concrete strength, as well as the plate thickness. The contribution of steel plates to the shear strengths of beams is greater for the lower internal shear reinforcement ratio. They also stated that the shear strength of a beam with web-bonded steel plates increases with increasing plate depth and thickness across the beam section.

2.3 REINFORCED CONCRETE BEAM

The property of the beam is important because it may affect the behavior of the RC beam shear strengthened with FRP. The larger beam size will cause the smaller average shear strength of the concrete (Bazant et al. 2007). Besides, the beam size also affects the shear enhancement of the FRP and its debonding failure show that the shear strengthening is better in larger strengthened beam (Lu et al. 2009).

In the other hand, Qu et al. (2005) had found that the beam size only have a very little effect to the shear enhancement effect. Leung et al. (2007) also showed that the shear enhancement can affect by beam size but with the larger beam size having less shear enhancement. Bousselham and Chaallal (2008) also state that most of the shear strength models are based on the result with small dimension of beam size which less than 450mm.

2.4 CONCRETE

Concrete is an artificial material similar in appearance and properties to some natural limestone rock. It is a manmade composite, the major constituent being natural aggregate such as gravel, sand and fine particles of cement powder all mixed with water. The concrete undergoes a process of hydration of the cement paste, producing a required strength to withstand load or force.

Numerous researches have been carried out to determine the suitability of coarse aggregate. Ohler, (1999), investigated that for one mix ratio (1:2:4) the suitability of coarse aggregate in concrete production. Olanipekun et al., (2006), investigated the comparative cost analysis and strength characteristics of concrete produced using replacement materials as substitutes for conventional coarse aggregate.

In a research conducted by Adewoyi et al (2008), Ogbomosho Nigeria on the comprehensive cost analysis and the compressive strength of concrete using periwinkle as full replacement for coarse aggregate in concrete with a mix ratio of 1:2:4 and 1:3:6. A gradation of 100%, 75%, 50%, 25% and 0.1% and a total of 300 standard cubes were cast and tested. The result showed that the compressive strength of the concrete decreases as the percentage increases with a consequent cost saving of about 14.8% and 17.5% for 1 m^3 of 1:2:3 and 1:3:6 respectively.

2.5 ISSUES WITH SHEAR- STRENGTHENING OF RC BEAMS WITH FRP

The researcher had led a series of design models which adopted in design guidelines and generally built upon the following simplifying assumption. The externally bonded FRP shear reinforcement contributes to the shear capacity of strengthened beams and the angle of the shear crack with respect to the horizontal beam axis is always assumed to be 45 degree for simplicity although the test shear crack angle can be either smaller or larger than 45 degree. The shear capacity of the strengthened beam can be calculated as a sum of the contributions of concrete, internal shear reinforcement and shear-strengthening FRP based on simple superposition.

2.5.1 Effect of Shear Span Ratio

The shear failure of RC beams is complex and shear tension failure for large span may occur due to failure mode. According to Chen, (2010), he had identify four type of shear mechanisms for concrete in RC beam which consist of shear stresses in uncracked concrete, aggregate interlock and friction, dowel action of the longitudinal reinforcement and arching action. The importance of the contribution of an individual mechanism depends on the specific beam properties and loading condition. He also stated that there is still no consensus on a unified shear design approach. Some approaches are suitable for shear tension failure while others appear to be particularly useful for deep beam failure.

Bousslham and Challal (2004) had revealed that most of the existing studies were conducted on beams with a/d ≥2.5 where the shear failure process is usually dominates by the development of the diagonal shear crack. Although some research involves two or more of the shear span to depth, the effect of the ratio is not the major objectives in these studies. There is a lack of research to provide a complete picture RC beam for greater coverage of the shear failure mechanism the proportion of the span to depth ratio.

The behaviour of deep beams shear strengthened with FRP is worthy of special attention. Islam et al. (2005), have shown that both the failure mode and the FRP shear resistance mechanism of deep beams has shown that the FRP shear failure and resistance mechanisms of these two modes of deep beams are completely different from those in beams with a/d > 2.5. Directly expansion of existing design methods established normal reinforcement beams knowledge is unacceptable. Islam et al. (2005), conducted the investigation and shown that the method is not available. It can easily be used to predict the shear capacity of FRP reinforced Improvement of the deep beams.

2.5.2 Effect of Beam Size

Bazant et al. (2007) had stated that the beam size has at least two effects on the behaviour of RC beam shear strengthened with FRP. A large beam size results in smaller average concrete shear strength. This size effect has been extensively studied but has not been appropriately reflected in most of the structural concrete code. It is generally agreed that the size effect is caused by tension-softening materials behaviour of concrete under tension and compression. The next effect is the beam size affect the shear enhancement effect of FRP. Lu et al. (2009) have shown that FRP- shear strengthening should be more effective in larger strengthened beam because larger beams having greater depth leads to larger FRP bond lengths. For debonding failure, the beam size also affects the shear interaction between internal steel stirrups and externally bonded FRP.

Besides that, Qu et al. (2005) found that the beam size had very little effect on the shear enhancement effect when FRP U- strips were used while Bousselham and Chaallal

(2004) showed that the gain in shear resistant tended to decrease with increasing effective depth of beam. Their research were supported by Leung et al. (2007) clearly showed that the shear enhancement can be significant different for strengthened beams with different sizes of the beams. Larger beam size is having smaller shear enhancement. The existing models may be rather optimistic and may lead to unsafe design for large beams. More experimental as well as theoretical work is required to clarify the issues of size effect.

2.6 MECHANISM PROPERTIES OF STEEL PLATES WRAPPED BEAM

2.6.1 Shear Strength

The FRP strips or plates can be bonded to the sides in different number of configuration to enhance the shear strength of RC beams. FRP rupture at lower stress than its tensile strength can cause shear failure of the strengthened beams. The actual failure behaviour depends on the bond conditions, the available anchorage length, the FRP's axial rigidity, and the concrete strength.

According to Sinan and Yagmur, (2013), strengthening the RC structures with externally bonded steel members is effective technique to improve the seismic bahaviour. Arslan, Sevuk and Ekiz, (2006), also agree that the strengthening of the damaged beam with steel plate would be desirable if rapid, economic, effective and simple strengthening technique. The plate bonding technique is becoming preferable for strengthening because it is easy construction work and it is minimum change in overall size of the structure after plate bonding.

The beam which retrofits by the steel plate will affect the shear strength of the beam. According to Holloway and Teng, (2008), the external bonding of steel plate on RC beams able to strengthening the structure. Bousselham and Chaallal, (2008) had do the existing studies and had shown that most of the studies are focus on flexural strengthening. The deficient of the RC beam have required the shear strengthening and it's due to different causes. The flexural failure is depend on the shear failure because the more ductile and allow stress redistribution and provides warning to occupants.

Shear strengthening using retrofit with steel plate is much less investigated and documented in previous literature compared to flexural strengthening with steel plate. The consensus on the design approach against shear failure for RC beams probably due to the complex nature of shear failure. This had cause difficult to develop a predictive strength model suitable for design against failure in strengthened RC beams (Bousselham et al. 2008).

2.6.2 Deflection

In deflection of mid-span of the beam is obtained from the test. The deflection is measure at the center of the section and two points at the mid span of the beam. The deflection of the beam was calculated by integration of the curvature along the beam (Abdelhady Hosny et al. 2006).

According to the K.C. Panda, 2013, his experiment had shown that the control beam having maximum deflection and corresponding to the failure load of 100kN. The midspan deflection of strengthen beam which retrofit with steel plate in shear zone is less if compare to controlled beam. The ductility is measured by calculated from the ratio of the deflection corresponding to the ultimate load to the yield load.

2.6.3 Cracking Pattern

The cracking on the beam is important because it may lead to failure of the beams. Besides that, the cracking pattern on the failure beam also can determine the strengtheners of the beams. Chen (2010) had shown that the debonding process of FRP U-strips is much more complicated than others type of FRP side strips. The slips between FRP and concrete at two sides of the critical shear crack are different for an FRP U- strip. The slips and bonding below the critical shear crack are assumed to be the same as those above it.

The effect of the bond between the concrete and the steel stirrups is complex. It can cause the crack pattern and the process of crack propagation in a complex manner which turn affects the development of stresses in stirrups and the FRP U- strips.

Chen (2010) also mention the concrete to the shear strength of the system is reduced at high values of FRP strain, and that the FRP rupture strain used in design should be reduced to account for the effects of curvature at the corners and in-plane sliding deformations along the critical shear crack.

2.6.4 Compressive Strength

The compressive strength is the capacity of a concrete to withstand vertically directed pushing force. According to Gunasekaran, Annadurai, & Kumar (2013), most of the compressive strength development took place in the early stages of curing and continues to increase with age indicating that the aggregate concrete did not deteriorate once the aggregates are encapsulated into the concrete matrix.

Besides that, Olanipekun, Olusola, & Ata (2006), stated that the compression durability of the concrete reduced as the amount of the replacement materials improved in the two mix percentages, there were 1:1:2 and 1:2:4. It was noticed that the concrete compression durability of the cube samples improved with improving age. The results further revealed that qualities 20 and 15 lights and portable concretes could be acquired if the amount alternative stages of the traditional rough combination.

On the other hand, according to Maninder, &Manpreet (2012), declared that the compressive strength of the concrete decreased as the percentage of the replacement materials increased. Therefore, the compressive strength of replacement materials aggregate concrete would be increased when the conventional aggregates have been replaced by 50 percent of coconut shell aggregates.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

In order to accomplish the objectives of this research, there are several experiment will be conducted. They are shear strength test, deflection test and also determine the crack pattern on the beams. Each of the tests has its own machinery to test. Therefore, in this chapter, the ways to carry out those tests and procedure to use these machineries is described.

3.2 RESEARCH DESIGN

This research is through doing experimental work and determines the strengtheners of the beams which retrofit with the steel plates. The experiment is carry out in the concrete laboratory in Universiti Malaysia Pahang (UMP). All the materials buy from the dealer and use the instruments in the laboratory. The experiments carry out from February 2014 to May 2014. The experimental work is guide by lecturer and technician in the laboratory. During the experimental work, the safety is very important. The rules regulation is important to make sure everyone is safety in the laboratory. The experiment is determined the shear strength, beam deflection and cracking pattern on the beams by flexural test.