Repair and Strengthening with CFRP on Concrete Slab Structure of Structural Crack due to Shortage Reinforcement Footstool

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Abstract- This research is a case study on building suffered structural damage floor plate, due to improper installation of reinforcement in the concrete floor plate pedestal, above the bearer beam. Because of extensive reinforcement installed As smaller then As result of the design, causing cracks in the structure of the joint between the slab with beams bearer. For that need improvement and strengthening of the structure, in order to be able to function again as its original design. In order to generate the improvement and strengthening appropriate, then the repair and strengthening is done must go through three stages, namely a very important stage of the investigation, the stages of evaluation and implementation phases. Materials used for repair and strengthening are the material Carbon Fiber Reinforced Polymer plate (CFRP plate), which serves as a substitute for the reinforcement shortage that has been installed. Furthermore, an investigation of structural damage, including cracked behavior of concrete slab on a pedestal beams, severity of the damage and the main factor causing the damage. The next stage: the first capacity analyzes, which is necessary nominal tensile strength of the existing concrete slab based workload plan, which both perform a capacity analysis of structures based on the vast floor plate reinforcement installed, then calculates the difference between nominal powerful need with strong nominal installed. The third is to analyze the needs improvement and strengthening based on the nominal value of the difference powerful need with strong nominal installed, followed by the implementation of the improvement and strengthening. Results of repair and retrofitting is, using 2 CFRP plate 1,2X50X1200 mm on each pedestal plate above the beam bearer, able to increase capacity until reaching 133.06% of the load serviceability.

Keywords- *Concrete Floor Plate, Structure Crack, Retrofitting, CFRP*

I. INTRODUCTION

Repair concrete structures are often done both during construction or when the structure is already in operation. The aim is to restore the structure to its original state without any addition of capacity in a weight-bearing structure. On the other hand, many concrete structures that need to increase the capacity of the burden, such as the structure of the bridge, because the traffic load increases, the structure of the building is converted, or damage due to faulty design or implementation error, the concrete structures in coastal areas (pier, beach tower and others) often experience corrosion in reinforcement, which resulted in a weakness capacity, so it needs strengthening.

In order to produce optimal repair and retrofitting, it must be done three important stages, namely: the investigation, evaluation and implementation.

The third stage is very important to do, and no one more important stage than the other stages. Because if one of the stages: investigation, evaluation or implementation is not done, then the results will not be maximized.

Therefore, the three stages of this must be done, and is done by experts are professional, experienced in the repair and retrofitting of concrete structures. Implementation of research applications as retrofitting CFRP Concrete Structures that have been made include:

A. Bending retrofitting in concrete beams using CRFP plate material.

Mohsen Shahawy et al (2001), made form of a T beam concrete specimen loaded by bending loads, as shown below.

There are two models Specimen: Model specimen 1 (1 piece specimen) without wrapping CFRP plate, and a second specimen models 7 pieces wrapped specimen with CFRP plate full mounted two layers in cross section beam, namely in the field of bending along the beam.
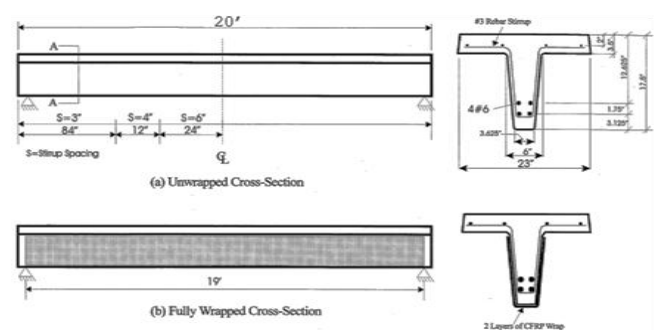

Figure 1.   Specimen Details (Mohsen Shahawy et al, 2001)

All specimens tested in laboratory with the same load.

Test Set-up: specimen was given a concentrated load (see Figure 2), the work load is gradually increased every 8.90 kN until the specimen collapsed. Pedestal using Elastomeric custody, the load is monitored using a combination of Load Sell on beam, and digital press gauges on the hydraulic line.
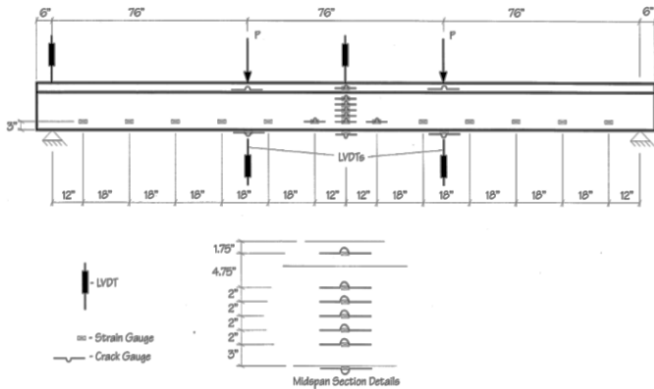

Figure 2. Loading Instrumentation Details (Mohsen Shahawy et al, 2001)

The test results of all specimens compiled in Table 1 below.

TABLE I. TEST RESULTS OF TEST SPECIMEN

Gir-der No.	Speci-men	M_{loads} kNm	My, kNm	Mu, kNm	Δy, mm	Δu, mm
1	C0 – 0L	-	3,96	5,25	33	137,20
2	F0 – 2L	-	4,48	6,39	40,64	101,60
3	F65 – 2L	2,57	4,71	6,33	35,56	81,28
4	F85 – 2L	3,42	4,51	6,42	38,10	101,60
5	F117 – 2L	4,68	4,40	6,40	35,56	93,98
6	F85 – 3L	3,35	4,74	6,43	38,10	88,90

Increased retrofitting of the girder specimen using CFRP bandage compared with those without wrapping CFRP, for specimen (F0-2L) yield increased of retrofitting moment My = 65%, for the specimen (F117-2L) for My = 85%. Whereas the limit moments (Ultimate) of Mu = 117%.

For additional CFRP second layer bandage can improve the retrofitting between 14-21% at the moment of ultimate load than without bandage (C0-0L). On the addition of a third layer CFRP, can add to increasing retrofitting of 7 and 11%. For structural rigidity, the first two layers of CFRP use of bandage can reduce the maximum deflection of 36% compared with that without bandage (C0-0L), and the addition of a third layer may reduce deflection by 9.0%. Graph moment versus deflection middle of span shown in the following figure.
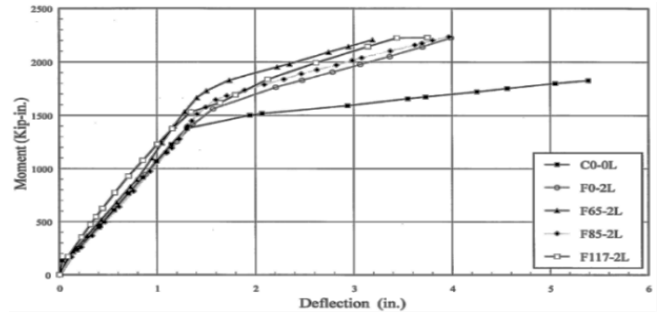

Figure 3. Moment versus deflection on midspan (Mohsen Shahawy dkk, 2001)

B. Column Analysis of Reinforced Concrete strengthened with CFRP.

Marolop Tua Sianipar (2009), conducted research concrete column with dimensions of 400/400 mm square cross section, using the main longitudinal reinforcement 8 D20 with stirrup $\varnothing$10, which is is strengthened with CFRP material thickness = 0.3 mm, which was wrapped on the outside of the column as restraint.

Using concrete material with compressive strength fc' = 25 MPa, yield stress reinforcement fy = 400 MPa, and the columns are axial and bending load. As a result, the strength of concrete is wrapped CFRP reaches fc '= 29.364 MPa, mean compressive strength of concrete increased by 17.456%. Axial load capacity increased by 23.906% and the bending moment capacity increase of 133.198%.

C. Experimental Behavior of CFRP sheets are attached to the concrete surface using CFRP anchor.

Research by Niemitz C. et al (2010), did Fabrication and anchor FRP bond during absorption of FRP sheets and embed them into the holes have been drilled in the concrete medium. This paper presents the experimental results highlight the complex behavior between FRP sheet and anchor. The main failure mode of the sheet-anchor system that can be identified according to experience. Experiments to identify the main variables that affect the behavior of FRP anchor sisem-sheet. This study contributes to the necessary experimental database that will assist in the future development of this anchorage system design recommendations.

D. Structural Behavior of Composite R C Beams with Externally Bonded CFRP.

Performed by G. Spadea et al (1998). The goal is to shape the behavior of the structure of reinforced concrete beams strengthened with external plastic sheets wrapped carbon fiber (CFRP). Consists of four blocks, three with CFRP sheet wrapped on the field visit, and two of them are equipped with an external anchor on the end pieces designed carefully at the whole landscape, were tested under four-point bending load along the span of 4.8 m. Tests conducted under displacement control. Wide beam instrumented to monitor strains, deflection, and bending due to loading on the entire spectrum of total failure, and to determine the structural response to the load of composite beams. The results showed that bonding CFRP

sheets in the field of tensile reinforced concrete beams, without consideration of the pressure of the anchor and slip juxtaposition between the field and the concrete media. External anchors carefully designed, can causing work preservation composite of failure to bear loads and the transformation of brittle failure, and can increase the load capacity of up to 70%, large enough for restore ductility of the structure, and the more ductile in fighting failure.

II.   METHODOLOGY

A. Research design - Specimen draft Preliminary and Testing Laboratory

Preliminary test object is form of material Carbon Fiber Reinforce Polymer (CFRP) as a partial replacement reinforcement, made to test its tensile strength. Testing methods follow the provisions of the American Standard Testing Materials (ASTM) D 3039 / D3039M-00: Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials (5). In accordance with the way the formation is shown as the following figure, and size standards are shown in Table 2 below.

TABLE II.   STANDARD DIMENSIONS CFRP SPECIMEN

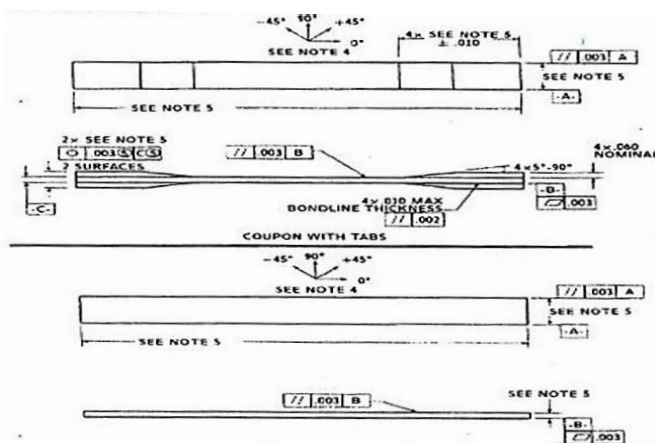| Materials	Thickness (mm)	Width (mm)	Length (mm)
Carbon Fiber Polymer	1,20	15,0	250,0

Figure 4.   Pull test CFRP specimen Model (ASTM, 2000)

Procedures and requirements for the implementation of the tensile test, described by visualizing an image as a requirement of testing:

1) Figure 5 is a wrong test procedure, where the specimen is not wedged perfectly on the tensile test tool the causing slip, specimen did not perfect break, so as not to generate tensile strong accurately.

2) Figure 6 is the correct testing procedures and specimen broke up perfectly so as to produce the actual tensile strong.
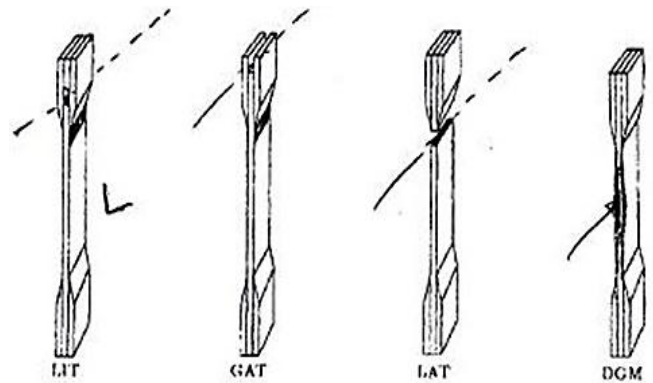

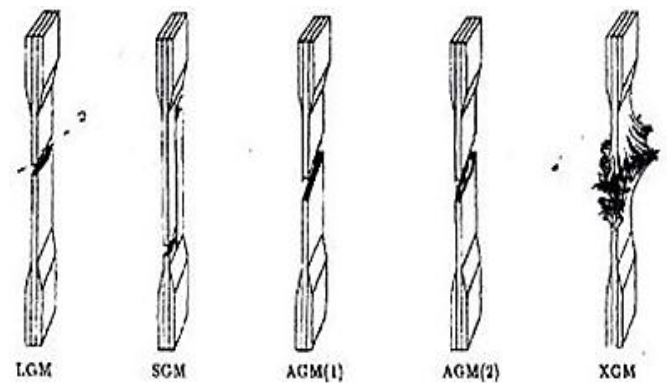Figure 5.   Implementation test of specimens is wrong (ASTM, 2000)

Figure 6.   Implementation test of specimens is right (ASTM, 2000)

When the specimens testing method is true, then the results of the tensile stress-strain curve relationship will be like Figure 7 below.
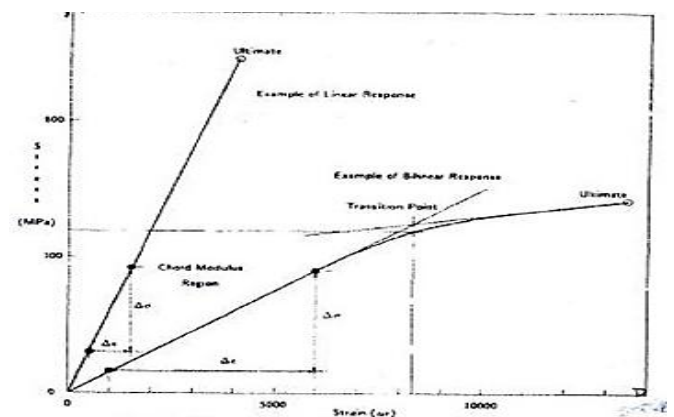

Figure 7.   Tensile stress-strain curve relationship of specimen (ASTM, 2000)

III. DISCUSSION

A. Standard of work load on the Slab and Property

Life load for classrooms in accordance with

SNI-03-1727-2002 = 4,00 kN/m2

Dead load:

- Ceramic layer + species……...= 1,20 kN/m2
- Self weight plate =0,12 (24)…= 2,88 kN/m2

Total of dead loads, q_D= 4,08 kN/m^2

Load by factor on the Slab:

- Life load = 1,6 (4,0) ………..= 6,40 kN/m^2
- Dead load = 1,2(4,08) ……...= 4,90 kN/m^2

Total load q_u = 11,30 kN/m^2

The material Properties:

- Concrete compressive strength fc' = 25 MPa.
- Reinforcement Slab used $\varnothing$10 mm
- Steel yield stress fy = 280 MPa.
- Slab thickness h = 120 mm

Moment on Slab:

Comparison of span Slab: $\frac{Ly}{Lx} = \frac{4,50}{4,00} = 1,13$
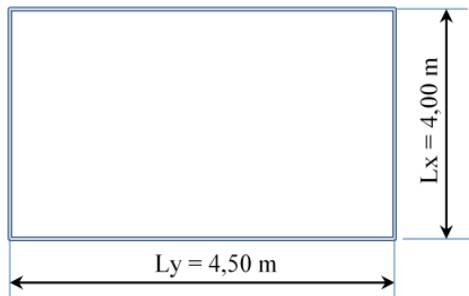

Figure 8. Schema pinched of elastic plate 4 side

Due to continuous slab system, then used a table pinched of elastic plate 4 side:

tx for lx = 48 (interpolation)

ty for ly = 47 (interpolation)

Moments:

Mtx=Mlx=0,001(qu).lx^2.tx= 0,001 (11,30).4^2.48 = 8,68 kNm/m

Mty =Mly = 0,001(qu).lx^2.ty=0,001(11,30).4^2.47= 8,50 kNm/m

Effective thickness Slab:

dx = 120-20-1/2(10) = 120-20-5 = 95 mm

dy =120-20-10-1/2(10)=120-20-10-5=85 mm

B. Reinforcement directions Lx:

$$\rho_b = \frac{\beta_1.0,85.fc'}{fy}\left(\frac{600}{600+fy}\right) = \frac{0,85.0,85.25}{280}\left(\frac{600}{600+280}\right) = 0,043$$

$\rho_{max} = 0,75. \rho_b = 0,75 (0,043) = 0,032$

$$\rho_{min} = \frac{1,4}{fy} = \frac{1,4}{280} = 0,005$$

$$M_n need = \frac{Mu_x}{\varphi} = \frac{8,68}{0,8} = 10,85 \ kNm/m$$

$$R_n = \frac{M_n perlu}{b.d^2} = \frac{10,85.10^6}{1000.95^2} = 1,20$$

$$m = \frac{fy}{0,85.fc'} = \frac{280}{0,85.25} = 13,18$$

$$\rho_{need} = \frac{1}{m}\left(1 - \sqrt{1 - \frac{2m.R_n}{fy}}\right) = \frac{1}{13,18}\left(1 - \sqrt{1 - \frac{2.13,18.1,2}{280}}\right)$$

$$= 0,0044$$

$\rho_p < \rho_{min}$, used $\rho_{min} = 0,005$

As = ρ_{min}. b. dx = 0,005(1000).95 = 475 mm^2

Used rebar$\varnothing$10–150=524mm^2>475mm^2 (OK)

C. Reinforcement directions Ly:

$$M_n need = \frac{Mu_y}{\varphi} = \frac{8,50}{0,8} = 10,63 \ kNm/m$$

$$R_n = \frac{M_n perlu}{b.d^2} = \frac{10,63.10^6}{1000.85^2} = 1,47$$

$$m = \frac{fy}{0,85.fc'} = \frac{280}{0,85.25} = 13,18$$

$$\rho_{need} = \frac{1}{m}\left(1 - \sqrt{1 - \frac{2m.R_n}{fy}}\right) = \frac{1}{13,18}\left(1 - \sqrt{1 - \frac{2.13,18.1,47}{280}}\right)$$

$$= 0,0054$$

$\rho_{min} < \rho_p < \rho_{max}$, … (OK)

As = ρ_p. b. dx = 0,0054(1000).85 = 459 mm^2

Used rebar$\varnothing$10–150=524mm^2>459mm^2(OK)

D. The Slab Moment capacity :

Toward Lx:

T=As ada.fy = 524(280) = 146720 N

$$a = \frac{T}{0,85.b.fc} = \frac{146720}{0,85.1000.25} = 6,90 \ mm$$

$$Mn = T\left(dx - \frac{a}{2}\right) = 146720\left(95 - \frac{6,90}{2}\right)10^{-6} = 13,43 \ kNm$$

φMn = 0,8 (13,43)

= 10,74 kNm > Mu = 8,68 kNm … (OK)

Toward Ly: T = 146720 N ; a = 6,90 mm

$$Mn = T\left(dy - \frac{a}{2}\right) = 146720\left(85 - \frac{6,90}{2}\right)10^{-6} = 11,97 kNm$$

φMn = 0,8 (11,97)

= 9,57 kNm > Mu = 8,50 kNm … (OK)

Bone conditions installed in Implementation Field rebars is installed $\varnothing 10 - 150$ Reinforcement footstool installed $\varnothing 10 - 300$, with an area of rebars As = 262 mm² Area deficiency of reinforcing footstool: = 524-262 = 262 mm²

E. Moment capacity mounted pedestal

$$a = \frac{T}{0,85.b.fc} = \frac{262 \cdot 280}{0,85.1000.25} = 3,45 \; mm$$

Mn=As.fy(dx − a/2) = 262. 280 (95 − 3,45/2).10⁻⁶=6,80 kNm/m

φMn = 0,8 (6,80)

= 5,44 kNm < Mu = 8,68 kNm… (not OK)

Conditions installed rebars this is the cause cracking on joint footstool the Slab with supporting beams.

Moment capacity deficiency on footstool:

= 8.68 to 5.44 = 3.24 KNM / m

To resolve these shortcomings will made by installing a retrofitting material CFRP plate type S512.

The total installed capacity shortage moment along footstool X

Mn = 3,24 . 4,5 = 14,58 kNm

F. Design of CFRP plate requirements and Patching Mortar material

Property CFRP:

- Tensile Stress fy = 2520 N/mm²

- Modulus Elasticity (E) = 165 kN/mm²;

- Density = 1.6, thickness = 1.2 mm, width = 50 mm.

Patching Mortar properties:

- Sikadur 30 Normal.

Stress block concrete diagram on support.
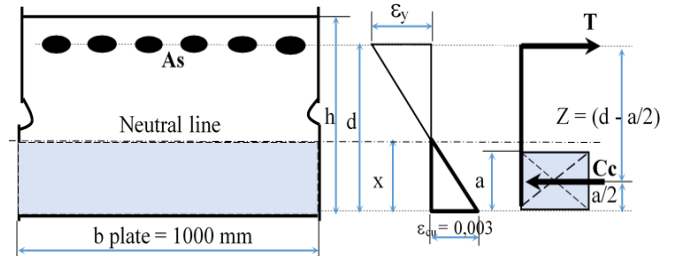

Figure 9.   Concrete Slab stress block diagram

Based on the Tensile strong capacity CFRP, then residual of Mn = 14.58 kNm which must be borne by the CFRP will be converted into Tensile force.

T = Mn / (d - a / 2) = 14.58. 106 / (95 - 1.725) = 156 312 N

CFRP sectional dimension of 1.2/50 mm, then section area = 1.2 (50) = 60 mm2

Tensile a rod CFRP capacity:

T = 60 (2520) = 151 200 N

Requirement a segment of slab:

= 156312/151200 = 1.034 ≅ 2 sticks.

Be installed 2 rods CFRP with a length of 1.20 m and the distance between the rods is taken 0.70 m. Schema application can be seen in Figure 10.

The increase in capacity with the addition of two CFRP:

= 151 200 (95-1.752).10⁻⁶.(2) = 28.19 KNM.

Moment capacity Mn/m:

= 28.19 / 4.50 = 6.26 kNm/m.

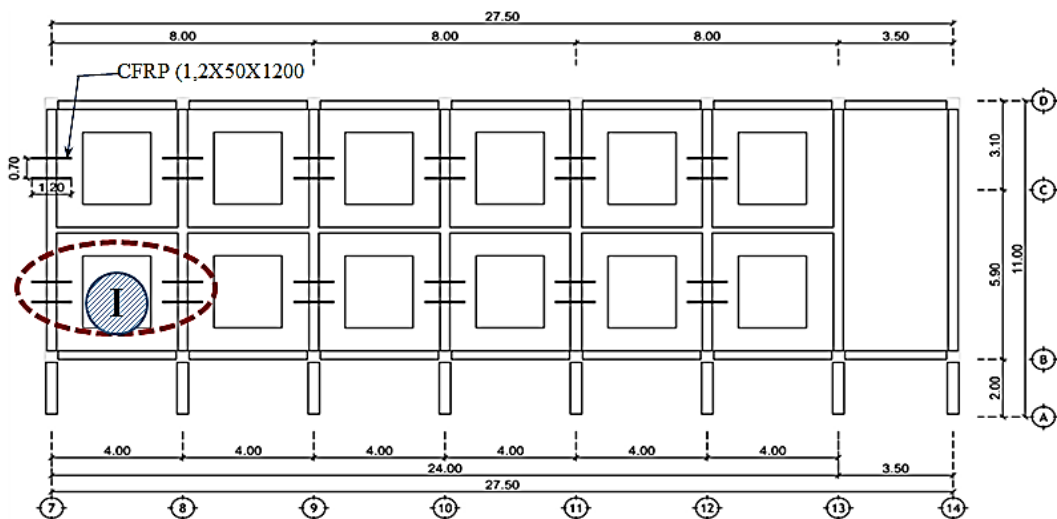The total Capacity moment Mn = 5.44 + 6.26 = 11.70 kNm > Mu = 8.68 kNm ... (OK).

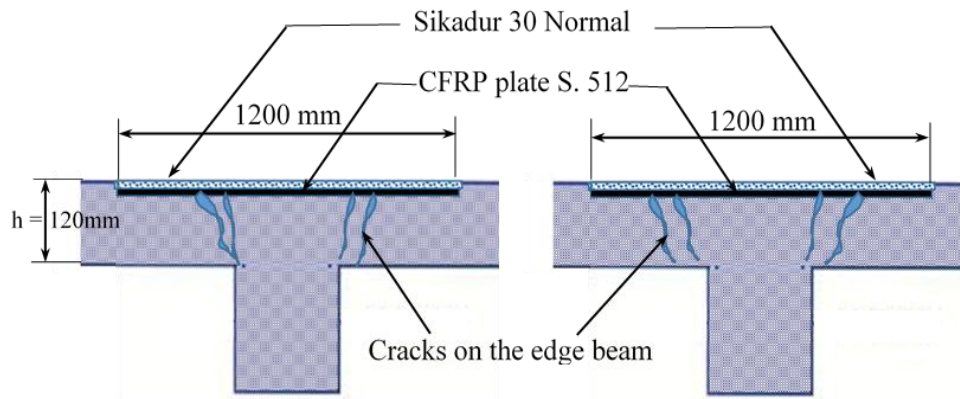Figure 10. Plan Design of Location Installation CFRP

Figure 11. Detail I, Aplication CFRP

G. Tensile Test and Applied of CFRP on Concrete Slab Structure - Preliminary manufacture Specimen

Manufacturing procedures follow the provisions of the American Standard Testing Materials (ASTM) D 3039 / D 3039M-00, with an odd number minimum of 3 samples. In this research were made 7 pieces samples with sizes as listed in the following table.

TABLE III. DIMENSIONS AND AMOUNT CFRP SPECIMENS

No.	Specimen	Function	Tick(mm)	Width(mm)	Length(mm)
1	Carbon Fiber Reinforcement Polymer (CFRP)	As a substitute for tensile reinforcement / flexuralr	1,20	15,40	250,00
2			1,20	15,00	250,00
3			1,20	15,25	250,00
4			1,20	14,70	250,00
5			1,20	15,00	250,00
6			1,20	14,50	250,00
7			1,20	14,90	250,00

Standards actual dimensions of 1.20 X 15.00 X 250.00 mm, but the size is listed in the table cannot be precise as standard. Because of the difficulty forming properly, the slab is composed of fibers, the fibers are often irrespective so that the edge of the plate width cannot be precise as wide as 15.00 mm, and however the size of the width is still within tolerance.

Figure 12. CFRP plate size 1.20 X 50.00 X 1000 mm

Specimens CFRP making process in the visualization as some pictures shown below.
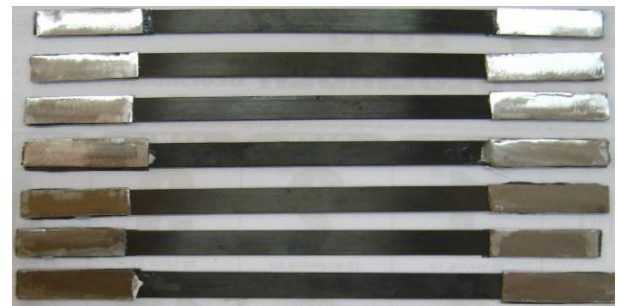

Figure 13. CFRP cutting process

Figure 14. CFRP specimen that has been formed (7 pieces)

H. Test Spesimun CFRP in laboratory

Do testing specimen in one by one using a tensile test machine of Universal Testing Machine (UTM) with a capacity of 500 kN. From 7 Specimens were tested worked well as 5 specimen, whereas are 2 specimen failed due to a slip at the end of the specimen clamps. Although there are 2 Specimens that have failed, but still meet the requirements of the amount due is more than 3 Specimens and odd number. Testing process document is shown in the following pictures.
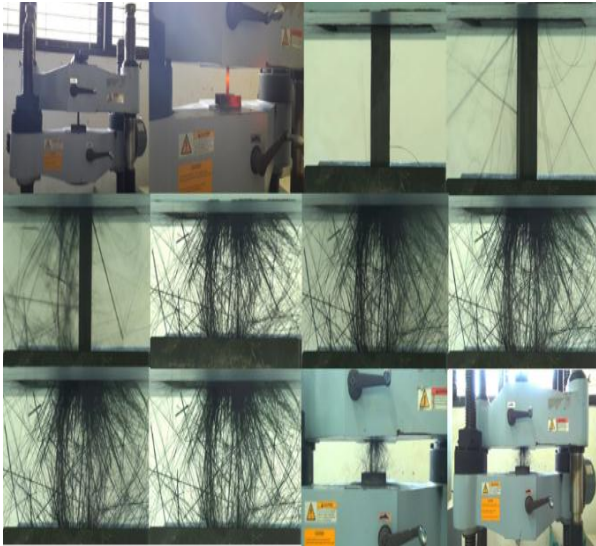
Figure 15. TensileTest Specimens CFRP process

After the specimen is removed from the testing machine UTM, reconfiguration into conditions have been broken up, forming CFRP fibers can be seen clearly, and documentation can be seen in the image below.

Figure 16. Archive Specimens CFRP who have dropped

From the image readable work tensile process given in specimen start from beginning to break up, after breaking up visible material specimen back to form fibers. Tensile test results are arranged in Table 4 below.

TABLE IV. TENSILE TEST RESULTS 5 SPECIMEN

| No. | Dimension of Specimen | | | Section Area (mm^2) | Tensile Force max. (kg) | Tensile Stress max. (fs) | | Yield Tensile Stress(fy) (MPa) | Yield Tensile Stress(fy) Standard Produsen(MPa) | Strain Max. (%) |
	Tick (mm)	Width(mm)	(fy)			Kg/mm^2	N/mm^2(MPa)			
1	1,20	15,00	250,00	18,00	5970,12	331,67	3253,72	3111		4,6133
2	1,20	15,25	250,00	18,30	6491,13	354,71	3479,67	3005		4,7000
3	1,20	14,70	250,00	17,64	5829,91	330,49	3242,14	3231	-	4,4807
4	1,20	15,00	250,00	18,00	5743,87	319,10	3130,41	2889		4,6240
5	1,20	14,90	250,00	17,88	6143,79	343,61	3370,84	3132		4,6513
Strong Avarage					6035,76	335,92	3295,36	3073,60	2520,00	4,6140
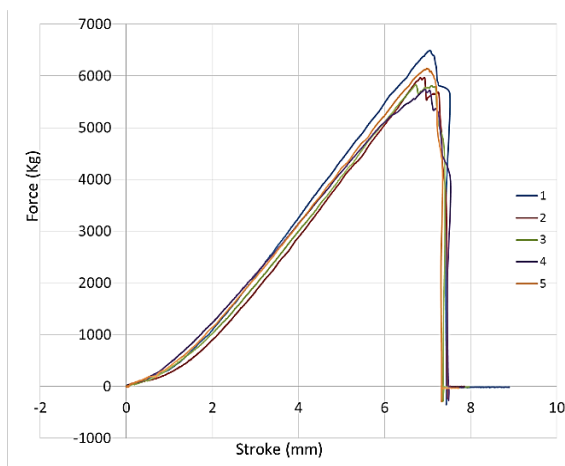
Figure 17. Relationship Force-Strain curve Specimens combined 1 s / d 5

Tensile powerful look of CFRP specimen in laboratory test results yield tensile, an average of fy = 3073.60 N / mm2, the increase from standard manufacturer significant enough are value by fy = 2520 N / mm2. Thus it can be concluded that CFRP is used in the field is very strong because it has a capacity above from the analysis that has been done.

I. CFRP Applied Process on Concrete Slab

Subsequent research activity is doing the repair and retrofitting of the structure are problematic concrete Slab, through the following stages:

J. Cleaning of concrete surfaces

This activity is carried out before the detailed investigation of the area damage on Slab along the edge beams which is where footstool slab.

Figure 18. Implementation process and results Patching

K. Measurement and Marking

Doing work measurement to determine the mounting point CFRP in accordance with the design. These measurements were performed before executing Patching on concrete surface for placement of the installation of CFRP. To determine the precise location of CFRP, the concrete surface be clearly marked on each installation location. Documentation activity measurements are shown in the following figure.

Figure 19. Implementation of Measurement and concrete surface markings

L. Patching Concrete Surface

Patching is doing dredging work the concrete surface size of 50 X 1200 mm according to the size CFRP plate with a depth up to the surface of the reinforcement plate on footstool floor beams. Implementation using Patching machine, the knife is set equal to the width of the plate widen CFRP = 50 mm. Image documentation Patching implementation is as follows.

M. Installation of CFRP on Concrete

After completion of the work Patching then the next process is the installation of CFRP on points concrete surfaces that has been in Patching. The orders of execution were as follows:

1. Cutting CFRP with appropriate design of each element length is 1200 mm CFRP using cutting tool grinding.

2. Epoxy CFRP surface is only one area that will be attached to the surface of the mortar Sikadur 30 Normal, are used specifically to glue the old concrete with CFRP. To form the species as an adhesive CFRP with concrete, Sikadur 30 Normal consists from components A and B. Both of these components in the form of liquid visco, mixed in the ratio 1: 1 and then stirred with a mixer so that homogeneous.

3. Installation of species on points the holes that has been cleared beforehand such that the flat surface of the concrete slab.

4. Installation of CFRP on location that has been mounted species, with a grace period of maximum ± 10 minutes after the installation of specific species so that are not already hardened are can lead to failure of the bond between mortar Sikadur 30 Normal with CFRP.

5. Shortly after pasting CFRP is carried out with a mini roller flattening presses and run evenly throughout the CFRP to generating the bond with mortar perfectly.

A whole series of CFRP application implementation is shown visually in the following pictures.

Figure 20. CFRP installation process

N. Analytical analysis according CFRP Tensile Test results

Based on the strong yield tensile results of CFRP the average in laboratory for fy = 3073.60 MPa, while the strong yield tensile value from standard manufacturer only of fy = 2520 MPa, then the analytic analysis will be calculated based on test results Strong yield tensile in laboratory.

Tensile one rod CFRP capacity:

T = 60 (3073.60) = 184 416 N

Needs one segment of slab:

= 156312/184416 = 0.85 ≅ 1 rod.

In actual fact only needed one CFRP rod, but the application on Slab structures remain attached 2 rods CFRP with dimensions 1,2X50X1200 mm. So that the capacity of the concrete slab structure to carry the load serviceability into:

2 CFRP =184416(φ=0.8)(95-1,752) .10-6. (2)

= 27.51 KNM. Moment capacity Mn/m= 27.51/4.50 = 34.39 (0.8)/4.50= 6.11 kNm/m.

Total Capacity moment of Mn = 5.44 + 6.11

= 11.55 kNm > Mu = 8.68 kNm ... (OK).

Thus, the structure of the concrete slabstrengthened by CFRP plate S.512, to be very strong, because the capacity of the structure be 133.06% to assume load serviceability.

Figure 21. The mixer process and installation of CFRP species

IV. CONCLUSION

From the Analytical analysis and tensile test results CFRP in laboratory, it can be concluded:

1. Test results of yield tensile force CFRP S.512 in laboratory better than the standard specified by the manufacturer.

2. Analytical Analysis results, require one rod CFRP plate rods only with dimensions 1,2X60X1200 mm on each footstool concrete Slab, but installed on the structure of 2 rods, so that the structure becomes very strong.

3. Repair and Strengthening results of concrete Slab structure is very strong, because Mu = 8.68 kNm and φMn = 11.55 kNm, capacity increased until reaching 133.06% than load serviceability load.

REFERENCES

[1] ACI 201.1R, 1992 "Guide for Making a Condition Survey of Concrete in Service".

[2] ACI 364.1R, 1993 "Guide for Evaluation of Concrete Structures Prior to Rehabilitation".

[3] ACI 440, 2000 "Guide For Design and Construction of Externally Bonded FRP Systems For Strengthening Concrete Structures", January 2000.

[4] The American Concrete Institute (ACI 318M-08), 2008 "Building Code Requirements for Structural Concrete and Commentary" First Printing June 2008.

[5] Desgnation ASTM D 3039 / D 3039M-00, 2000, "Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials", Commities ASTM D-30 on compsite Materials, Published July 2000.

[6] Dharma Astawa Made, 2006: "Concrete Structures I", Modules Teaching, Department of Civil Engineering-FTSP, UPN "Veteran" East Java, ISBN: 978-979-1005-21-0.

[7] FIP, 1985 "Inspection and Maintenance of Reinforced and Prestressed Concrete Structures", London

[8] FIP, 1991 "Repair and Strengthening of Concrete Structures", London

[9] G Spadia, F Bencardino, RN Swamy, 1998. "Structural Behavior of RC Composite Beam with Externally Bonded CFRP" American Society of Civil Engineers, ISSN (online) 1943-5614, published 01 August 1998.

[10] Hartono, 2008 "Repair and Strengthening Concrete Structures", Civil Engineering Seminar papers UPN "Veteran" East Java.

[11] Lawrence C. Bank, 2006. "Composites for Constrution (Structural Design with FRP Materials)", Published by John Willy & Sons.Inc, Hoboken-NewJersey.

[12] Marwan Bilkasem SA, Abdul Aziz bin AS, et al, 2014. "Shear Strengthening of Reinforced Concrete Beams Using Carbon Fiber Reinforced Polymer Laminate", American Journal of Civil Engineering (AJCE), Vol.2, No. 1, Published, June 2014.

[13] Niemitz C, James R, Brena S, 2010. "Experimental Behavior of Carbon Fiber Reinforced Polymer (CFRP) Sheets Attached to using CFRP Concrete Anchors", Journal of Composites for Construction, Volume 14, Issue 2, April 2010.

[14] Nor Norazman M, et al, 2013. "Carbon Fiber Reinforced Polymer (CFRP) as Reinforcement for Concrete Beam", International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com, ISSN. 2250-2459, Volume 3, Issue 2, February 2013.

[15] Mohsen Shahawy et al (2001), "Flexural Strengthening with Carbon Fiber-Reinforced Polymer Composites of Preloaded Full-Scale girders" ACI Structural Journal / September-October 2001.

[16] Reference of Sika's, "Strengthening and Repair Projects" entire project than year 2000 to 2013.

[17] SNI-03-2847-2002, "Procedure for Calculation of Concrete Structures for Buildings", National Standardization Agency (BSN), Jakarta.

[18] The Concrete Society Technical Report No. 55, "Design Guidance For Strengthening Concrete Structures Using Fibre Composite Materials", 2000

[19] Technical data of Sika's Product, than the year 2000 to 2014.

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