

Reinforcement on existing concrete that has been reinforced with CFRP

(Case study of a box culvert bridge on a Toll Road in Semarang, Indonesia)

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ABSTRACT

Implementing a box culvert system on bridges is an economical choice due to the reduced material use. This system has a joint that blends between the slab and the abutment walls and pillars. With a stiffer joint, the moment that occurs is smaller than a simple beam system. Box culvert foundations are commonly shallow foundations. Consequently, it is vulnerable to settlement, particularly the abutments that receive soil loads from the bridge embankment. Therefore, making the displacement in the abutments greater than in the pillars.

The existing box culvert structure at the study site in Semarang, Indonesia has a span of 2 x 15 meters. Reinforcement has been previously carried out using Carbon Fiber Reinforced Polymer (CFRP) to treat cracks. Though, as time passed, the treated cracks reopened and new cracks developed. Structural cracks occur at a negative moment, so that the reinforcement yielded.

A reinforcement using CFRP does not increase stiffness—thus, a reinforcement with adding external reinforcement system is used. This reinforcement is done by adding 400 x 200 WF profile—connected mechanically by attaching anchors to the slab. Reinforcement with a WF profile is safer due to its mechanical system, which makes it easier to implement and monitor.

Keywords: Box culvert, structural cracks, WF profile

INTRODUCTION

Constructions with reinforced concrete would gradually deteriorate. Deterioration stems from several aspects, such as environmental factors, stability of foundation, usage rate, operational factors, etc. As a result, deterioration reduces the functionality of constructions that use reinforced concrete.

The existing bridge / underpass box used in this case study is located in a Toll Road in Semarang, Indonesia, and was built in 1988. The structure of this bridge consists of fused two-span box culverts. This structure uses a reinforced concrete structure. The total span of the bridge is 30 meters, consisting of walls and slabs that serve as abutments, pillars and bridge floors. This structure serves as two-level road intersections with a slanted / oblique shape. Both the upper and lower roads consist of four lanes in two directions. Interruption on traffic on the upper road is strictly prohibited. An illustration of the box bridge is shown in Figure 1.

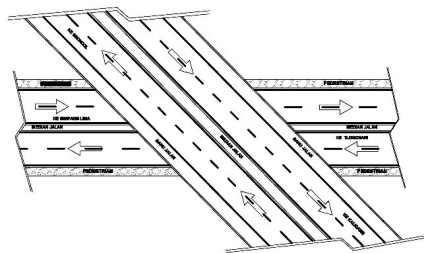
The use of shallow foundation causes a settlement, especially on the abutment side, which experiences a greater displacement. Due to differential settlement, there is an additional load, which increases the negative moment on the pillars. Furthermore, this results in cracks on the abutment. Although efforts have been made to reinforced this structure using Fiber Reinforced Polymer (FRP) and injection of cracks with epoxy resin. Cracks are visible to the naked eye, which indicates that the cracks that occur are structural cracks. Figure 2.a. shows the cracks occurring on the underside of the slab near the abutment. Figure 2.b. is an image from the side of the box bridge, where cracks are visible on the upper-side of the slab near the pillars and the abutments.

The abutment wall / support area on the underside appears to have been reinforced using FRP with a tight fit (30 cm) and the cracks have been closed using resin injection. However, it is evident that the results of those treatments are not optimal, because even though the cracks have been injected with resin, some have either reopened or developed new cracks. These cracks are visible to the naked eye, even in a distance. And thus, it can be concluded that these cracks are structural cracks. Reinforcement with FRP, which is expected to be able to treat and prevent cracks by increasing the bearing capacity of the slab, seems to not have been entirely successful.

Problem formulation

Currently, there is a problem in the slab structure where whole cracks can be found, especially in the slabs that support the abutment wall. It is evident that the slabs near the abutment wall on the north and south sides have been reinforced using CFRP (Carbon Fiber Reinforced Polymer), namely by adding high quality fiber which functions as additional reinforcement in the affected area. In addition, the cracks were injected with epoxy resin. But it appears that the cracks that were patched appear to have reopened or moved, and even new cracks have occurred elsewhere. Those cracks are visible to the naked eye, and therefore, it can be concluded that the width of the cracks is rather large. To ascertain its strength, it is necessary to conduct research on the structure, namely to determine the feasibility of the structure and the level of safety for people passing on both roads where the traffic is usually very congested.

The research was conducted to determine the safety level of the structure due to the deformation that has occurred. The results of field and laboratory tests, as well as field observations, are then used to analyze. The results are then compared to the guidelines / standards to conclude the condition the structure of the box culvert bridge. If the conclusion confirmed the presence of structural parts that do not meet the requirements in terms of strength or service capability, a reinforcement effort becomes necessary. The reinforcement must ensure that the carrying capacity of the structure is able to carry the design load.



Source: Own work (2017).

Figure 1. Illustration of box culver bridge

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Source: Own work (2017).

Figure 2.a. Cracks on the underside of abutment; 2.b. Cracks on the upper-side of pillars

LITERATURE REVIEW

The existing structure has been reinforced with Carbon Fiber Reinforced Polymer (CFRP). Nevertheless, the results have not been optimal, considering the new cracks appearing and old cracks reopening (see Figure 2.a.). CFRP or fiber-reinforced plastics are composite materials made of a polymer matrix that is reinforced with fibers, such as glass, carbon, or aramid. Although other fibers such as paper, wood or asbestos are sometimes used (Masuelli, 2013). In its use, CFRP is combined with an adhesive (Epoxy Impregnation Resin) which will attach the fiber sheets to concrete blocks.

Flexural reinforcement with another method is by adding external reinforcement. Research on the effect of flexural reinforcement with steel slabs on the behavior of T-beams of bridges (Sukrawa, 2006), namely by adding steel slabs to the underside of reinforced concrete beams. More specifically, reinforced concrete beam with a span of 3750 mm, body dimensions of 112,5 x 212,5 mm, flange of 425 x 50 mm and slab reinforcement of 1,4 x 96,4 mm. Compared to beams without any slab reinforcement, there was an increase in bending capacity of 65,4%.

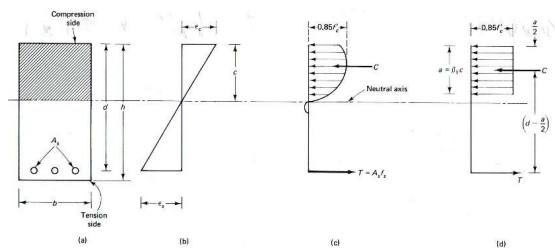
In the study of the behavior and bending capacity of reinforced concrete beams with steel slab reinforcement (Nomi et al, 2014), with 2 mm thick reinforcement slabs on a 20 x 30 cm beam with a span of 300 cm, there is an increase in bending capacity of 84,62%. Unreinforced beams that have been load tested until the first crack appeared are then reinforced with 2 mm slabs, which increased their capacity by 69,23%.

According to Nawy (2003), the magnitude of the bending moment capacity at the concrete cross-section is shown in equation (1). If $C = T$, then equation (2) can be used.

$$Mn = As fy \left(d - \frac{a}{2} \right) \quad (1)$$

$$Mn = 0,85 fc b a \left(d - \frac{a}{2} \right) \quad (2)$$

Increasing the flexural capacity of the concrete cross-section is feasible by adding steel on the tensile side, which results in greater distance / arm ($d-a/2$) (see Figure 3.d). According to equations (1) and (2), the moment capacity Mn will increase. Thus, by increasing the external steel cross-section, the bending capacity can be increased. The magnitude of which, is a function of the cross-sectional area of the steel and the distance.



Source: Nawy (2003).

Figure 3.a. Concrete cross-section; 3.b. Strain; 3.c. Actual stress block; 3.d. Equivalent stress block

RESEARCH METHODS

Secondary data on the existing box bridge was not found. The data needed for the analysis are as-built drawings and material quality. Technical drawings and analysis of reinforcements that have been carried out with CFRP were also not found. Therefore, to conduct a feasibility analysis of the structure, testing and measurements are carried out to obtain sufficient data. Field research activities carried out include observation and inventory and field-testing procedures, such as concrete hammer test, rebar scans and obtaining core-drilled concrete specimens. Core-drilled specimens are tested for compressive strength in the laboratory.

Observation and inventory

Field observations reviewed the physical condition of the concrete elements in detail, namely damage to structural elements, cracks / spalling, deformation, etc. Inventory in the field is in the form of geometric measurements of constructions and structural components.

Field testing

1. Concrete hammer test

This test is carried out to map the uniformity of concrete quality. The tool used is Silverschmidt concrete hammer. Test method used is the *Standard Test Method for Rebound Number of Hardened Concrete ASTM C 805-06*.

2. Rebar scanning

Because there are no detailed pictures of the reinforcement, scanning is done on the concrete elements to find out the embedded reinforcement. The tool used is Hilti PS 300, which can detect reinforcement embedded in concrete to a depth of 200 mm.

3. Obtaining core-drilled specimens

To obtain the compressive strength of concrete (f_c'), the specimens are extracted from the existing concrete. Method of obtaining and testing used is the *Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete ASTM C 42/C 42M – 04*

4. Measurement of deformations

Deformations appear on the abutment side. On Figure 4, it appears that settlement of the abutment north side (smaller angle) is greater in comparison to that of the pillars. Elevation was measured by using a waterpass.

5. Measurement of the width of the cracks

Cracks are visible to the naked eye, which indicates that there is a structural crack. The width of the cracks was measured by using a micro crack meter.

Testing in the laboratory

The core-drilled specimens were brought to the laboratory and tested for their compressive strength using a compression tool. Testing in the laboratory enables us to figure out the quality of existing concrete.

Analysis of the structure

Analysis is carried out to find out whether the internal forces due to loads can still be sustained by the structural elements. Thus, the feasibility of the structure can be determined. If it is not feasible, then reinforcement is carried out.

FINDINGS AND DUSCUSSION

Concrete hammer test

The test was conducted on abutment walls, pillar, and slab. The test results are shown in Table 1 through 4.

Table 1. The results of hammer test on the northern abutment wall

No.	Compressive Strength (kg/cm ²)
1	800
2	580
3	755
4	500
5	485

Source: Own work (2017).

Table 2. The results of hammer test on the center pillar

No.	Compressive Strength (kg/cm ²)
1	615
2	550
3	485
4	845
5	460
6	355
7	900
8	985
9	445
10	595

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Source: Own work (2017).

Table 3. The results of hammer test on the southern abutment wall

No.	Compressive Strength (kg/cm ²)
1	500
2	375
3	785
4	385
5	490

Source: Own work (2017).

Table 4. The results of hammer test on the slab

No.	Compressive Strength (kg/cm ²)
1	795
2	760
3	840
4	745
5	810

Source: Own work (2017).

Rebar scanning

The result of scanning the main reinforcement is: D 16-80 is used on the slab, while D 19-100 is used on the wall.

Testing of core-drilled specimens

Core drill was tested on abutments and pillars. The results as compressive strengths are as follows: $f_c' = 16,8$ MPa, 17,7 MPa and 34,6 MPa (see Table 5).

Table 5. The results of core drill test

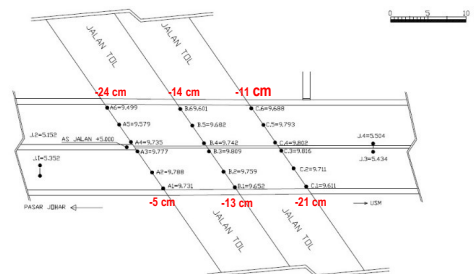
No.	Compressive Strength (kg/cm ²)
1	168
2	177
3	346

Source: Own work (2017).

Measurement of deformations

The biggest deformation that occurs is at -24 cm on the north side of the abutment (see Figure 4).

Deformations appear on the sides of abutment, whose displacement is greater than that of the pillars.



Source: Own work (2017).

Figure 4. The results of measurement of deformations

Measurement of the width of the cracks

Cracks that have been treated with injections reopened and / or developed new cracks—both on the pedestals of abutment and in the middle of the span. It can be seen on some cracks that water has managed to pass these cracks (see Figure 5).



Source: Own work (2017).

Figure 5. Cracks on the slab that has penetrated all the way to the bottom

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The presence of water in the cracks would potentially cause corrosion of the reinforcement. If the water leak is not resolved immediately, it will cause damage to the structure, which results in the decline of the functions of the structure.

The width of the cracks, as measured by the micro crack meter, varies in size. The measured widths of the cracks are 1,8 mm and 1,2 mm. This measurement was conducted on both recently-occurring cracks and cracks that have reopened after **previous reinforcement**. The permitted maximum width according to ACI is 0,4 mm. Thus, making a treatment necessary to prevent enlargement and / or development of new cracks.

From the observations of concrete cracks in the slab, it can be concluded that the cracks are very visible and exist in an ample amount, which occur at the pedestals of the abutment wall, which can be seen at the bottom. Meanwhile, the middle pillar wall displays fewer number of cracks that are barely visible. Most of the cracks that occur are structural cracks (width > 0,4 mm). In the next subchapter, the width of the cracks is measured and determined.

The crack patterns on the slabs on both the north and south sides have the same pattern, namely at an acute angle ($< 90^\circ$) and in a larger amount. Cracks at wider angles do not occur.

On the pedestal in the middle (pillar), the cracks occur on the upper-side due to the negative moment occurring on the pedestal, which leads to cracks developing on the upper-side of the slab (see Figure 6).



Source: Own work (2017).

Figure 6. Cracks in the slab above the pillars

Analysis of the structure

Observation, inventory, and field testing, as well as laboratory testing, are used to construct a structural modeling. The quality of the concrete is input according to the results of the compressive strength test of the core drill test object.

The load on the bridge used as a standard is SNI 1725:2016 *Pembebanan untuk Jembatan (Loading for Bridges)*. Based on SNI 1725:2016, the traffic load on the superstructure of the bridge is D Load, which consists of uniformed load and concentrated load.

The amount of uniformly distributed load is 9,0 kPa, with the length of its span 30 cm shorter. The amount of concentrated line load is 4,9 kN/m.

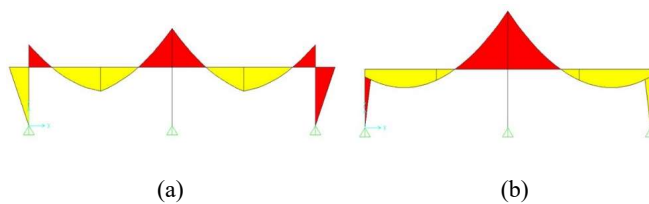
Additional load is the load due to displacement load from the measurement result of -24 cm.

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Load combinations that require to be reviewed are as follows:

Fixed load combination : 1,2 (DL) + 1,6 (LL)
Temporary load combination : 1,05 (DL + LLr + EL) (LLr = 0,3 LL3)

Figure 7 showcases the final moment that occurs due to dead loads, traffic loads and displacement loads. It can be seen, that the negative moments on the pillars increase and the negative moments on the abutments shifted to positive moments. With the help of an animation software, it can be seen, that even with a displacement load of 5 cm, the structure is unable to withstand the moment. Meanwhile, the maximum displacement that occurred was 24 cm.



Source: Own work (2017).

**Figure 7.a. Illustration of moment combination of dead load and live load;
7.b. Illustration of moment combination of dead load, live load, and displacement load**

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From the analysis, it can be concluded that the structural elements are capable to withstand both dead load and live load. However, if a displacement load is added, the structure is unable to withstand it. The displacement load analyzed is 5 cm at the lowest, which already indicates over-stress that occurs on the structure—despite the maximum displacement load that occurred being 24 cm. Therefore, it can be concluded from both the results of observations of the cracks and the results of the structural analysis that cracks will develop along with the addition of greater deformation. The sizes of the cracks that were chosen at a random, measured at 1,0 mm; 1,2 mm; and 1,8 mm.

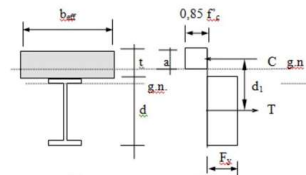
Severe cracks occur on slabs with small angles on both the north and south sides, this is due to several possible causes:

- Smaller angles (acute angles or right angles) result in a large stress concentration, making the possibility of stress greater.
- Settlement on the slab with small angle (smaller area) is bigger than a slab with wide angle (bigger area). (-24 cm and -11 cm in the northern side; and -21 cm and -5 cm on the southern side).
- Distribution of loads, especially live loads that are not equal when vehicles pass over it.

Cracks are expected to continue to develop along with the displacement in the structure, especially in the abutments. The settlement in the abutment is large because the embankment uses landfill. The embankment load is very large at 5500 kg/m². The soil load causes the box structure to experience differential settlement.

To restore the function of the construction to its original state, so that the construction can function as before, it is necessary to repair and reinforce the concrete and structural elements. Due to the bearing capacity of the slab being very small, along with the increasing displacement load, it is necessary to reinforce it by increasing the structural stiffness. The treatment is also necessary because the existing reinforcement using CFRP was not optimal and failed to stop the cracks. An effective reinforcement can be done by adding WF steel girders to hold the slab above it. These girders are connected with anchors; hence, they can mechanically blend with the slab in supporting the load. For the optimization, a WF 400 x 200 x 8 x 13 was used, with Hilti M16 anchor and a distance of 50 cm. The calculation of the girder reinforcement was done with: $a = 62,64$

mm; $d_l = 868,67$ mm; moment capacity (M_n) = 227 ton m > ultimate moment (M_u) = 98 ton m (see Figure 8).



Source: Nawy (2003).

Figure 8. Stress block on a slab cross-section with WF profile

CONCLUSION AND RECOMMENDATION

With the addition of WF profile reinforcement, there is a theoretical moment increase of 227 ton meters. The ultimate moment is a combined load of dead load, live traffic load (concentrated line load and uniformed load) and displacement load of 98 tons meters. The use of reinforcement with a WF profile is safer due to its mechanical system, which makes it easier to implement and monitor. The drawback from a WF profile reinforcement is the reduced vehicle's free space. Although, due to the addition of WF 400, the height of the box is still higher than 4,1 m.

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