Retrofitting and Investigation of Performance of Box Girder Bridge Using Glass Fiber Reinforced Polymer (GFRP)

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Abstract— Namosain box-girder bridge was located in Kupang City at Province of Nusa Tenggara Timur (NTT). This bridge was built in 2008 and recently suffered any cracks on the bottom of slab of the box girder during its service load. This bridge was retrofitted using *Glass Fiber Reinforced Polymer* (GFRP) to reinstate and improve its performance against live loading. Two layers of GFRP, one in longitudinal direction and another in transverse direction was bonded on the bottom of box girder using epoxy resin.
The stiffness of the bridge was improved significantly by evaluating its deflection before and after strengthening. Static loading test by using truck loading was performed after 30 days of retrofitting. Stiffness of the bridge was increased by 45% to 70%. Keywords— bridge, box girder, GFRP, static loading

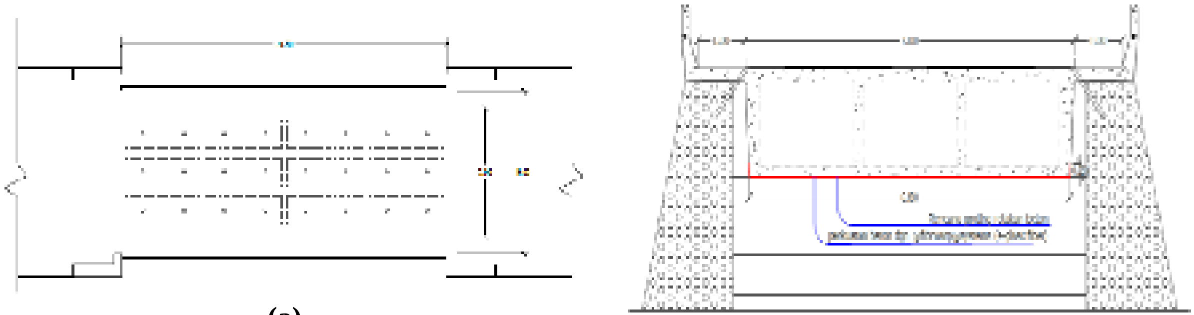
I. Introduction

Namosain box girder bridge was located at Jl. Pahlawan, in Kupang City Province of Nusa Tenggara Timur (Fig.1). This bridge was built in 2008 and in the early year of 2017 planned to strengthen due to cracks appeared at the bottom slab of the bridge. In addition, aggressive environment due to location near the sea can rapidly cause corrosion to the bridge (Fig.2). This bridge Fig.2 shows plan view and cross section of the bridge. The bridge was made of concrete with prestressing tendon as main bending reinforcement. This bridge has 24.8 m length, 7-meter width and 1.6 m height. The cross-section was three boxes beam with slope. This bridge was suffered any cracks on the bottom of the box girder during its service load so that performance of the bridges reduced. Therefore, strengthening with Glass Fiber Reinforced Polymer (GFRP) was determined to overcome this problem and to reinstate its function and improving its performance.

Figure.1 Location of Namosain Bridge strengthened with GFRP composite.

Figure. 2 Namosain box-girder bridge lay near the sea.

Applications of Glass Fiber Reinforced Polymer (GFRP) have been used and developed over the last few decades in construction industry [6]. Benefit of GFRP for strengthening system are corrosion resistant, high strength and light so that easy in repair construction. In flexural strengthening of RC beam using GFRP fabric, capacity load can be increased up to 75% compared with RC beam without strengthening [7]. As shear strengthening, GFRP fabric can improve shear capacity of a structure as well. Research showed that using GFRP as shear strengthening in form of strip at beam with less shear bars reinforcement, the load capacity increased 20.13% and GFRP gave contribution to shear strength up to 48.42 % [8]. Static load testing on this bridge was conducted using standard truck loading to know performance of the bridge after strengthening. This test was conducted before and after the bridge retrofitted. The position of truck was setup in such a way to get maximum moment condition in the mid-span of the bridge and resulted in maximum deflection as well.



(a) **(b)**

Figure 3. Plan View (a) and cross section (b) of the Namosain Box Girder Bridge.

2. Retrofitting the Bridge

Before bottom slab of box girder bridge was retrofitted using GFRP, any cracks was repaired using epoxy injection techique. Firstly, cracks were cleaned from dust and grease with wire brush and blowed up the cracks with compressor there. Then cracks slit were capped with bond compound and leave some spot for attaching Unifor port crack injector system for better penetration resin injection into the cracks (Fig.3). The injectror system utilised a low and constant pressure method to inject epoxy resin into fine cracks of all kinds of concrete structure. The system maintans the pressure of the grouting material to at least 1.0 kgf/cm^2 and limits its maxium to 3.0 kgf/cm^2. It needed at least 12 hours curing after the injection process finish to allow cracks closed and then Unifor system and seal can be removed using grinding.

Figure 4. Cracks repairing process.

Figure 5. Fiber sheet direction,cutting size, overlap and installation of order for strengthening system in half length bridge view.

Figure 6. Strengthening bottom slab of box-girder bridge using GFRP Tyfo SEH51A composite

After whole cracks repair process were completely finished, strengthening of the bottom slab of the box girder bridge was strated. Glass fiber sheet (Tyfo type SEH51A) combined with Tyfo S Epoxy which has a two-component epoxy for bonding application were used as composite system for external reinforcement for strengthening bridge. This GFRP composite has ultimate tensile strength of 575 MPa, maximum elongation of 2.2% and tensile modulus of 26.1 GPa [3]. Procedure for strengthening of bottom slab of box-girder bridge was described following. Firstly the required surface for strengthening was cleaned, dried and free of protrusions or cavities. Next, glass fiber fabric was cut as required length of 6.275 m and 1.28 m width. Cutting size of fabric fiber and orientation applied to the concrete slab surface showed in Fig.4. This dry fabric fiber was laid on wide plastic sheet to saturate with epoxy resin which has been prepared. The required surface length for strengthening was also painted with epoxy resin using large roll. Then the saturated laid fiber sheet was attached to the painted surface and using roll this sheet pressed to remove air trapped below the fiber fabric. This work was started from the left end bridge support along 6.275 m (Fig.5). The wide part with length of 6.275 m was finished first before continued along the bridge span. Overlap length of cutting fiber sheet was 100 mm. One layer of glass fiber embedded with epoxy was attached first to the bottom surface of the box beam along the bridge span of 24.8 m. Then the second layer with length of 6 m was attached in transverse direction or along wide of the bridge. It started from the left bridge support as well. Overlap 100 mm was also applied for the next 6 m length in transverse direction. The curring time for strengthening application need at least 30 hours.

3. Static Loading Test

Static loading test using standard truck loading was conducted in comply AASHTO LRFD Bridge Design Specifications year 2007 [5]. This test was performed twice, before the bridge strengthening and after strengthening. The aim of this test is to know quality of GFRP strengthening system by investigating deflection of the bridge at maximum loading condition. Fig. 6 and 7 shows plan view of bridge for setting of trucks loading. Bridge has two lanes, lane 1 toward Tenau port and lane 2 heading to Kupang city. The vertical dot lines shows mid-span of the bridge. For combination loading 1, two rear wheels of trucks lay on this mid-span to get influence line of maximum moment. This maximum moment also gives maxium deflection under this condition. As noted, one truck gives maximum load of 11 Ton.

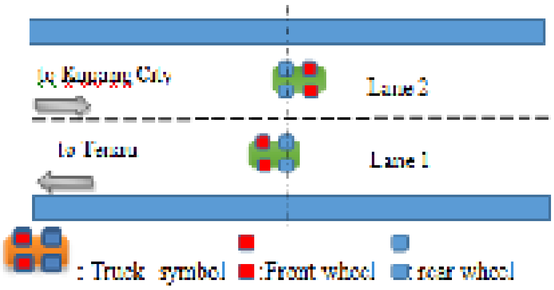


Figure 7. Truck loading on top slab of box-girder bridge. Both rear wheel of truck located on mid-span of bridge as combination 1.

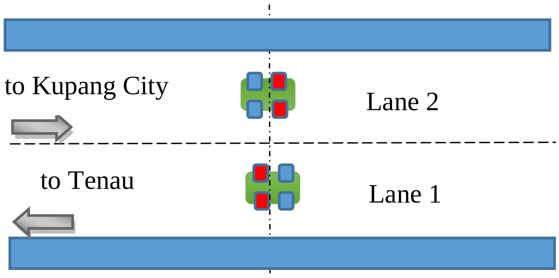


Figure 8. Mid-span Bridge located between load resultant and both rear wheels of trucks as combination 2

Fig. 7 shows each rear wheel of trucks move backwards about 43 cm from mid-span. Therefore mid-span is located between each rear wheels with load resultant from each truck. Maximum moment occurs below the rear truck. This gives slightly different maximum moment compared with combination 1, however this gives similar deflection with combination 1. Four dial gauges were located at mid-span of the bridge to measure deflection occur during loading test. Those position were depicted in Fig.8. At beginning, those all dial gauges were assumed to give similar result for deflection, however it gave different result between deflection at middle section of slab and deflection of slab near the edge of the box girder on strengthened bridge. Fig 9 shows position of dial gauges attached to the bottom slab of box-girder bridge. Fig. 11 and 12 shows position of rear wheels according to the loading combination 1 and combination 2.

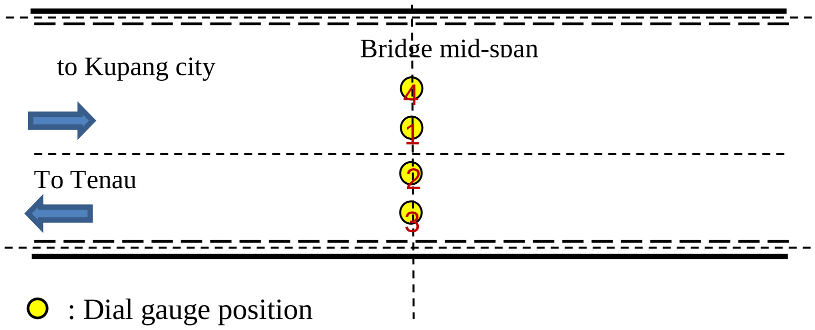


Figure 9. Position of dial gauge seen from top view.

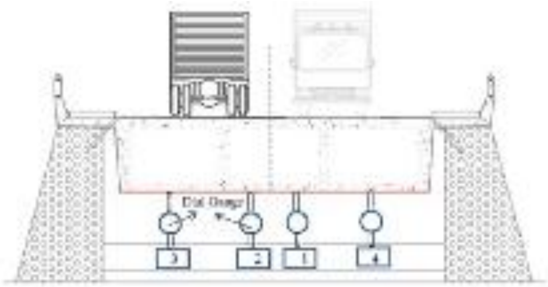


Figure 10. Dial gauges position seen from left view of cross-section

Figure 11. Two trucks at loading position on box-girder bridge that tested.

Figure 12. Position of rear wheels of trucks on loading of combination 1

Figure 13 Position of rear wheel of truck on loading of combination 2

4. Result and discussion

Table 1 and Fig.13 shows loading test result on slab of box-girder bridge with truck for combination 1. Before strengthening, maximum deflection at mid-span on dial 2 was 2.6 mm at load of 22 Ton. Dial 1,3 and 4 showed almost similar deflection value those were 2.50 mm and 2.55 mm. This meant that at the time bridge has not strengthened yet with GFRP, deflections got almost uniform at mid-span along the wide of bridge. After bottom of bridge slab strengthened, it occurred increasing stiffness of the bridge. Maximum deflection decreased to 1.40 mm on dial 1 and 2. The increasing stiffness using

GFRP was up to 46% at middle part. In addition, the increasing stiffness was more significant at outer part slab (at position dial 3 and 4) that was 74% - 76%.

Table 1 Loading test result on box-girder bridge for combination 1.

	Beban		before strengthening				after strengthening				Percentage for Combination 1			
6		Combination 1												
7	(Ton)		Dial 1	Dial 2	Dial 3	Dial 4	Dial 1	Dial 2	Dial 3	Dial 4	Dial 1	Dial 2	Dial 3	Dial 4
8	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
9	7.40	Empty truck	1.50	1.48	1.35	1.55	0.60	0.40	0.10	0.15	60.00	72.97	92.59	90.32
10	14.70	truck with half load	1.75	1.65	1.60	1.70	0.95	0.90	0.30	0.35	45.71	45.45	81.25	79.41
11	22.00	truck with full load	2.55	2.60	2.55	2.50	1.40	1.40	0.60	0.65	45.10	46.15	76.47	74.00

Fig.13 shows relationship between load and deflection before and after strengthening using GFRP. The dots line on graph shows deflection on dial 1 to 4. All four curves show deflection trend which are similar. However, after strengthening with GFRP composite system the curves shows different trend compared with previous curves.

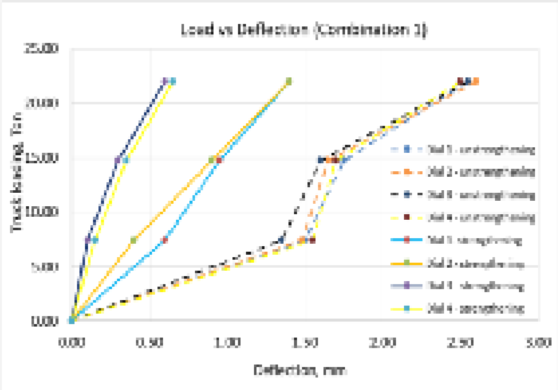


Figure 14 Truck loading vs deflection for combination 1.

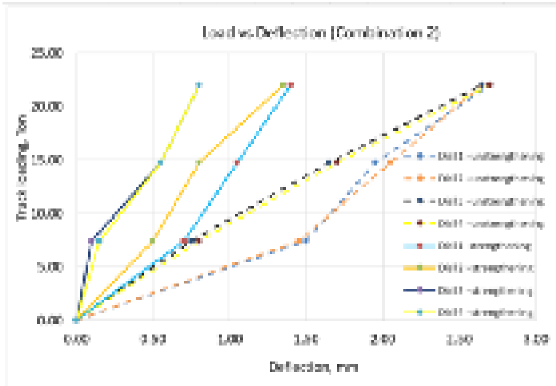


Figure 15. Truck loading vs deflection for combination 2

Table 2 and Fig.14 shows loading test result on slab of box-girder bridge with trucks for combination 12. Before strengthening and at maximum load of 22 Ton, maximum deflection at mid-span on all dials (dial 1 to 4) had almost similar value that was 2.65 mm – 2.70 mm. After strengthening using GFRP, these deflections were decreased significantly. Dial 1 and dial 2 showed deflection of 1.40 mm and 1.35 mm, whereas dial 3 and 4 showed decreasing deflection significantly to 0.8 mm. There was increasing stiffness of the bridge up to 49 %. Whereas dial 3 and dial 4 (outer side of slab) increased significantly to 70%.

Table 2 Loading test result on box-girder bridge for combination 2.

Beban		before strengthening				after strengthening				Percentage for Combination 2			
(Ton)	Combination 2	Dial 1	Dial 2	Dial 3	Dial 4	Dial 1	Dial 2	Dial 3	Dial 4	Dial 1	Dial 2	Dial 3	Dial 4
0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
7.40	Empty truck	1.50	1.45	0.75	0.80	0.70	0.50	0.10	0.15	53.33	65.52	86.67	81.25
14.70	truck with half load	1.95	2.05	1.65	1.70	1.05	0.80	0.55	0.55	46.15	60.98	66.67	67.65
22.00	truck with full load	2.70	2.65	2.65	2.70	1.40	1.35	0.80	0.80	48.15	49.06	69.81	70.37

Fig.15 and Fig.16 shows relationship between deflections and dial gauges position along wide of bridge at mid-span. The curves with dots lines shows bridge before strengthening, whereas solid lines shows otherwise. From the graph it is clear that stiffness of the bridge increase significantly near the edge of bridge slab, and middle part of slab the stiffness tend increase in uniform way.

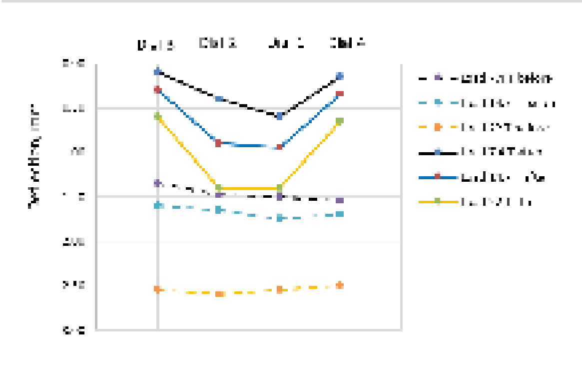


Figure 16 Relationship between deflections and dial gauges along the bridge width at mid-span of the bridge for combination 1.

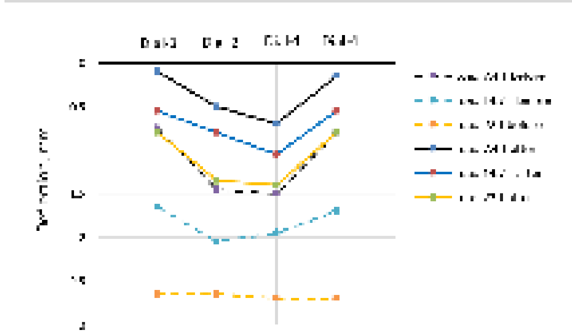


Figure 17 Relationship between deflections and dial gauges along the bridge width at mid-span of the bridge for combination 2.

5. Conclusions

Based on implementation, investigation and analysis, it can be concluded as follows:

1. There is stiffness improvement of the box girder bridge after strengthening using Glass Fiber Reinforced Polymer (GFRP).
2. Increasing the stiffness were 45% - 70% for combination 1 with trucks loading of 22 Ton. Maximum deflection of slab before strengthening was 2.6 mm and after strengthening decreased to 1.4 mm
3. Increasing the stiffness were 48% - 70% for combination 2 with truck loading of 22 Ton. Maximum deflection of slab before strengthening was 2.7 mm and after strengthening decreased to 1.4 mm.
4. According to AASHTO 2007, maximum allowed deflection for bridge is L/800, or 31 mm for this bridge span of 24.8 m. Therefore, maximum deflection for this bridge with the truck loading is still less than permitted.

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