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The experience of retrofit design in using CFRP of building case study of the ramp structure of palm oil mill in South Sumatera

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Abstract. This paper was aimed to share our experience in using CFRP in the case of retrofit of the ramp structure in palm oil mill in South Sumatera with a total length of 104 m and a width of 20 m, which consists of the primary beams (30 cm x 70 cm) span 8 m, the secondary beams (25 cm x 40 cm), and the slabs (thickness 20 cm). This ramp was cracked in the beams and the slabs after the five-year operation. In the first-year operation, no crack was found. However, from the second year until the fifth year, the cracks increased. After investigating in the field, we found a flexure crack in the primary beams, the secondary beams, and the slabs. In the drawing, we found that the bar was a plane bar and the quality of the concrete average was fc' 20 MPa. The Imposed loads for the vehicular traffic were designed with 12 tons. In the next step, we made a static calculation to check all designs. The results from the static calculation were that the capacity of the bar was sufficient, and the deflection was still under the allowed limit. The cracks mostly occurred in the Ramp structure. In the parking area in another building, there was no crack found. Thus the solution for this ramp was repaired the concrete from the cracks then strengthen it using CFRP. Strengthening of the primary beams used two strips of a fiber-reinforced composite or plastic materialtype with a thicknessof 1.2 mm and a width of 10 cm. The capacity of the positive moment and the negative moment would increase the capacity about 64%. For the strengthening of the secondary beams using two strips of CFRP with a thicknessof 1.2 mm and a width of 10 cm,the capacity of the positive moment and the negative moment would increase the capacity about 145%. For the strengthening of the thickness of the slabs 20 cmusing one strip with a thicknessof 1.2 mm and a width of 10 cm,the capacity of the positive moment and the negative moment would increase the capacity about 186%. The use of CFRP as the strengthening of the beams and the slabs was significant in increasing the moment capacity for the beams and the slabs due to the increasing load acting on the structure, thus the structure was still safe to use.

1. Introduction

There are numerous Crude Palm Oil Mill built in Indonesia, and one of them is in South Sumatera. The Owner of the Mill assigned us to check the concrete structural building which in part of building some crack was found. The cracks was found mostly in the ramp area. The ramp has designed with capacity of 12 tons. According to information from employees the occurrence of crack is after several year operations. Cracks has found on the primary beams, the secondary beams, and the concrete slabs. The management was highly alarmed that the width of cracks in the ramp could be bigger, and it could harm the users. For that reason, we were given the responsibility to conduct a structural analysis and a retrofitting to ensure that the ramp was safe to utilize.

2. The existing condition of the beams

The analysis steps were collection of as-built drawing, the concrete quality check, and the field visit to visually examine the condition. The construction of the ramp structure can be seen in Figure 1a, in which the length of the ramp is 104 m and the width is 20 m. The space between columns is 8 m in both longitudinal and transversal. The plate was designed with a two-way slab with a span of 4 m. The dimensions of the primary beam are 30 cm x 70 cm, the secondary beams are 25 cm x 40 cm, and the slab thickness are 20 cm.

a) b)

Figure 1. a) the span of Oil Mill in South Sumatera, b) the structural condition

Meanwhile, the damage can be seen in figure 2. The type of damage was cracks in the primary beams, the secondary beams, and the slabs. The cracks occur along of the primary beams, the secondary beams, and the slabs. In accordance with the survey results, there was no significant deflection of the beams. No crack was found at the columns, and no differential settlement was also found in the foundation.

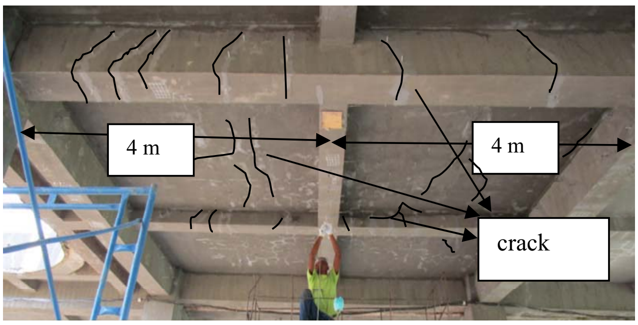

Figure 2. The cracks on the primary beams, the secondary beams, and the slabs.

The reinforcement of the primary beams (the rectangular beams) with a dimension of 30 cm x 70 cm, on the upper side of the support was 4 Ø 25 mm and the lower side was 2 Ø 25 mm, with the stirrups reinforcement of Ø 13 mm-150mm. Meanwhile, in the mid span, the upper side of the reinforcement was 2 Ø 25 mm and the lower side was 4 Ø 25 mm, with the stirrups reinforcement of Ø 13 mm-150mm. For the secondary beams with a dimension of 25 cm x 40 cm, the upper side of the reinforcement support was 3 Ø 16 mm and the lower side was 3 Ø 16 mm, with the stirrups reinforcement of Ø 13 mm-150 mm, while in the mid span, the upper side was 3 Ø 16 mm and the lower side was 3 Ø 16 mm, with the stirrups reinforcement of Ø 13 mm-150 mm. The thick of slab was 20 cm, with the support and the mid span concrete based on the as Built drawing was Ø 13 mm –150 mm.

The reinforcement of the primary beams, the secondary beams, and the concrete slabs of the ramp of Palm Oil Mill can be seen in figure 3, which are according to the as Built drawings that plain bar have been used. For the concrete according to the investigation it has been found that the quality of concrete around 20 Mpa. According to an Indonesian Standard, the concrete class is $f_{c'} = 20\ Mpa$ [1], and the steel reinforced class is BjTP 24 [2].

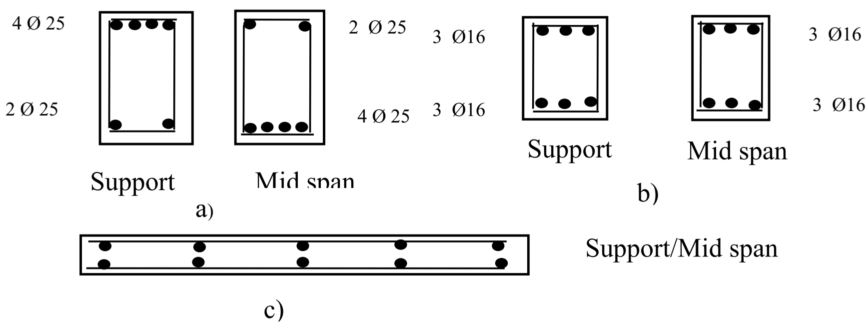

Figure 3. a) Existing primary beams, b) Secondary beams, and c) Slabs

3. Existing Structural Condition Analysis

In performing of a structural analysis the required data are as follows: The as-built drawings of the building, the result of the concrete quality check and the result of the field survey. The calculation was conducted with ETABS program, in which the working loads, Dead Load (DL), Asphalt Load + Rain Water Load = 1.0 kN/m^2, Live Load (LL) Vehicle Load = 120kN = 12 tons and Earthquake Load [3].

The drawing results of the bending moment and the shear-force on the beams can be seen in figure 4a and 4b. As shown, for the beams with the size of 30 cm x 70 cm, the maximum moment on the support was 224.63 kNm (negative moment), while the mid span moment was 144.2kNm (positive moment), and the shear-force which occurred on the support was 138.6 kN. For the beams with the size of 25 cm x 40 cm, the maximum moment which occurred on the support was 37.3 kNm (negative moment), while the mid span moment was 24.5 kNm (positive moment), and the maximum shear force was 25.8 kN.

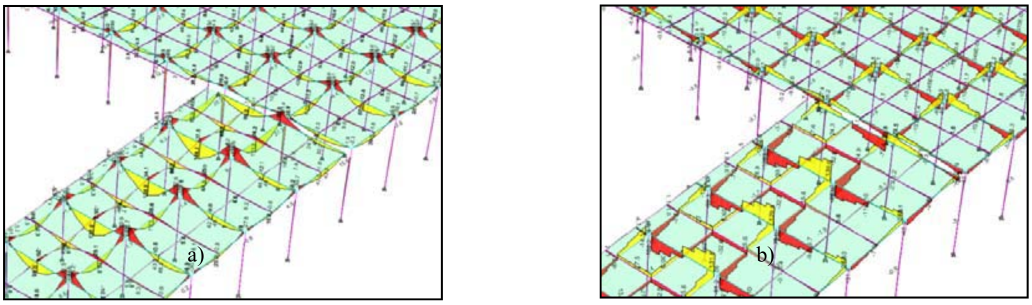

Figure 4. a) Moment on the primary beams and the secondary beams, b) The shear force on the primary beams and the secondary beams

Meanwhile, the floor slabs can be seen in figure 5, in which the maximum deflection occurred was 3.3 mm.

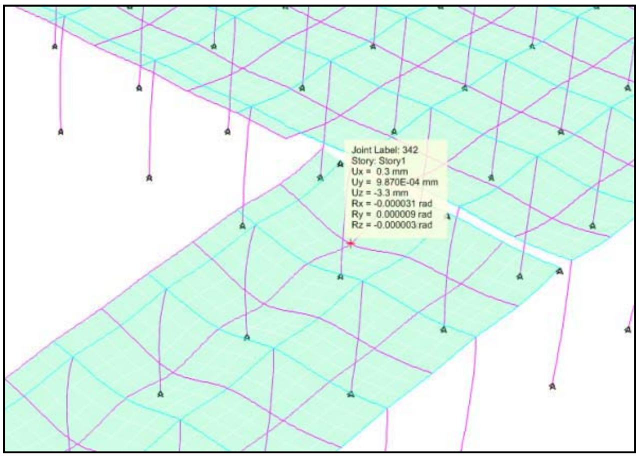

Figure 5. Deflection which occurred on the primary beams and the secondary beams

From the calculation results of the maximum moment, the shear force which occurred on the primary beams and secondary beams can be seen in table 1.

Table 1. The maximum moment and the shear force on Palm Oil Ramp structure

Beam	Negative Moment	Positive Moment	Shear Force
The primary beams 30 cm x 70 cm	224.63 kNm	144.2 kNm	138 .6 kN
The secondary beams 25 cm x 40 cm	37.3 kNm	24.5 kNm	25.8 kN

The principle of the reinforcement design is based on figure 6.

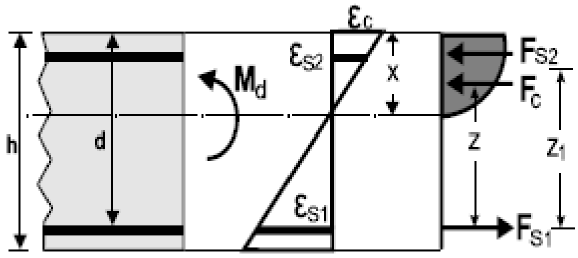

Figure 6. The strain diagram on the reinforced concrete beams

According to the calculation sheet ofprimary beams of 30 cm x 70 cm the reinforcement mid span was 2 Ø 25 mm in upper side and the lower side was 4 Ø 25 mm, whereas in the upper side of the support was 4 Ø 25 mm and the lower side was 2 Ø 25 mm. That's mean the primary beam is still safe.

For the secondary beams with the size of 25 cm x 40 cm, in which the upper side of the mid span reinforcement was 3 Ø 16 mm and the lower side was 3 Ø 16 mm, the moment capacity which occurred was $M_d = z_1 . Fs = 0.332 \times 65 = 21.58$ kN, while the moment which occurred was 37.3 kNm (unsafe for the negative moment).

Furthermore, the slabs with the reinforcement of Ø 13 mm – 15 cm, the moment capacity obtained was $M_d = z \cdot Fs = 0.166 \times 144 = 23.90$ kNm, and it was reasonably safe.
Based on the calculation, it can be concluded that the secondary beams were unsafe and need retrofitting.

4. Method of Retrofitting and Discussion

There are several methods in the retrofitting that are as follows:

a. By adding steel beams or plates under the concrete beams
b. Using Carbon Fiber Reinforced Polymer (CRFP)
c. Adding new columns
d. Using external pre stress on beams

After a nalysing have been done, the secondary beam was found to be unsafe because the flexural reinforcement of the secondary beams was too small. However, after discussing with the owners, the strengthening process was conducted not only in the secondary beams, but also in the primary beams, and the slabs to increase the moment capacity.

The selected method was the use of CFRP because this method was faster, and the mill might still be operated during the project implementation.

Based on the experimental study in the laboratory [4], the use of CFRP can increase the load as much as 81%, while based on [5-12] the use of CFRP can also increase the load. In Structural Laboratory of USU [13] the use of CFRP in beam can increase 1.887 times.

The mechanical property of CFRP used in this project was the carbon fiber reinforced polymer (CFRP) with an epoxy resin matrix, with a black color and a tensile strength (mean value) of 3100 N/mm^2, and a design value of 2900 N/mm^2. The modulus of elasticity was 148000 N/mm^2 with a thickness of 1.2 mm and a width of 100 mm.

The design principle [14-16] was based on Figure 7 FRP + epoxy, with a thickness of 1.2 mm, a width of 100 mm, and the calculation of the tensile stress of CFRP was 2800 MPa.

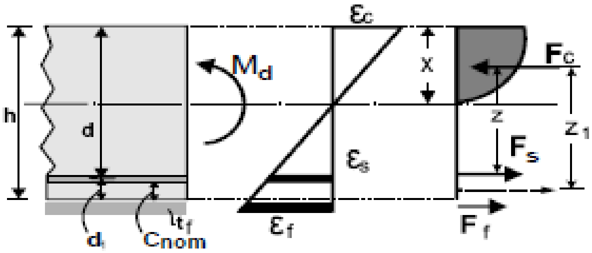

Figure 7. The strain diagram on the beams with CFRP [5]

For the primary beams and the secondary beams have been added with two strips of CFRP (thickness of 1.2 mm and a width of 100 mm), while in the slabs, one strip of CFRP with a thickness of 1.2 mm and a width of 100 mm was added. The calculation result can be seen in table 2, showing the moment capacity with and without CFRP.

As shown in table 2, adding two strips of CFRP on the primary beams increased the moment capacity by 64%. So in the secondary beams the addition of two strips CFRP increased the moment capacity by 145 %, while the addition of one strip CFRP on the slabs increased the moment capacity by 186%.

Table 2. The moment capacity on the primary beams, the secondary beams and the slabs with and without CFRP

Beams and Slabs	Moment Capacity with CFRP	Moment Capacity without CFRP	Increase of moment capacity
Primary beams of 30cm x70 cm	369.58 kNm	224.63 kNm	64%
secondary beams of 25cm x 40 cm	91.58 kNm	37.30kN	145 %
slabs thickness of 20cm	68.51kNm	23.90kNm	186%

The next step was the analysis of the cracks. There are three types of cracking which are physical crack, chemical crack, thermal crack, and structural crack. The types of cracks occurred in palm oil mill were the physical crack and the structural crack. Therefore, to repair the structural crack, CFRP was used, and physical crack was handled with chemical injection.

The retroffit of ramp structure can be shown in figure 8 which are CFRP have been used. Figure 8a showed the strengthening of the primary beams, figure 8b showed the strengthening process using CFRP in the secondary beams and the slabs, while Figure 8c showed the injection process at the cracks in the beams and the slabs.

a)

b)

c)

Figure 8. a) CFRP installation on the primary beams, b) CFRP installation on the secondary beams and the slabs c) injection at the crack of the beams and the slabs

5. Conclusion

After analyzing of the ramp structure in Palm Oil Millit was found thatthe flexure reinforcement on the secondary beams was found to be too small. The primary beams and the slabs were still safe. Nevertheless we suggest to made repairs not only for the secondary beam but also for primary beams and slabs.

In the selection of repair selected method was using strengthening with CFRP. The strengthening process was conducted by adding two strips of CFRP with a thickness of 1.2 mm and a width of 100 mm in the primary beams and the secondary beams, while only one strip of CFRP added in the slabs. Now, the improvement was finished, and the project operated well.

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