Behavior of Shear Connector Variations on Strengthened Reinforced Concrete Slabs Using Cold Formed Steel

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Abstract. The method of execution the installation of strengthened material on building structural elements is sometimes a problem because it requires special expertise and expensive. In addition, structural elements strengthened using mortars or additions concrete have shown a collapse that begins with the release of these strengthening material making it difficult to be composite. This research has been tried alternative strengthened using cold formed steel (CFS) profile that were bonded with Epoxy Sikadur CF-31 and Dynabolt M10 so that the strengthened material becomes composite with the existing slab. The purpose of this slab strengthened was to increase the capacity of reinforced concrete slabs to resist bending loads. Five concrete slab test have been made with dimension 45x145x12 cm with longitudinal reinforcement Ø10-140 mm and transverse reinforcement Ø8-650 mm. The four slabs are strengthened using CFS type C75, 0.75 with spacing of 200 mm. Two slabs use the Sikadur CF-31 Epoxy as glue (SSE) and the other two use Dynabolt M10 as shear connectors (SSD). Furthermore, a flexural test was carried out by given one point load in the middle of spans. The results have shown an increase in the flexural load capacity of SSE and SSD. Moreover, the use of Epoxy Sikadur CF-31 as a glue has increased the stiffness of the strengthened slab while the use of Dynabolt can maximize the ability of CFS to carry bending loads.

1. Introduction
The method of implementing the installation of strengthening material on building structural elements that have decreased capacity sometimes becomes a problem because it requires special expertise and proper accuracy. The development researched related to the selection of material that is easily applied continues to grow, such as the use of Carbon Fiber-Reinforced Polymers (CFRP) as well as the addition of the dimensions of the slab and the adding of steel area at the bottom of the slab. Those methods are relatively difficult in application in the field because it requires special expertise and expensive. In addition, research on structural strengthened using mortar or concrete material as reinforcement holders in the tensile area has shown the failure of strengthened structural elements. The collapse begins with the release of new mortar or concrete from the existing slab [1]. This occurs because of the lack of bonding between the mortar and the test object, in other words the sliding provider does not function properly so that the test object was not composite or works independently in receiving the load.

The usage of cold formed steel has also been tested with Dynabolt as a shear connector and has shown an increase in the peak load [2]. In term of increasing variation on the use of cold form steel profiles (CFS) as strengthened materials, shear connector variants were carried out i.e. Epoxy Sikadur CF-31 as glue and Dynabolt as a sliding connector. In this research, it is expected to be able to overcome the problem of complex implementation methods and be able to increase the capacity of reinforced
concrete slabs to resist bending loads. Previous study has shown that the cold formed steel has a higher tensile strength than the reinforcing steel. Mild steel yield stress reaches 542.8 MPa and maximum stress reaches 544.01 MPa [3]. The others advantage of light steel are easier to mobilize and carry out its construction.

2. Method

The study begins with an analysis to determine how many dimensions of the slab and the amount of reinforcement that will be needed to be reinforced concrete slabs based on under reinforced section [4] with the initial assumption is the maximum load limitation that can be giving by the slab test. In addition, the analysis with block stress according to Indonesian standard and a non-linear analysis with Response-2000 was also carried out according to the following model [5]. Due to the unavailability of CFS profiles in Response-2000, the modeling only uses reinforcement area as the CFS area as Figure 1.

![Figure 1. Model of strengthened specimen.](image-url)

The analysis results obtained slab dimensions 45x145x12 cm with longitudinal bars Φ10-140 mm and transverse bars Φ8-650 mm. The total number of specimens that have been made there are five. One sample as control slab (CS), two samples for strengthened slabs with CFS and Sikadur CF-31 and also two other samples strengthened with CFS and Dynabolt M10. The Dynabolt data refer to previous studies with shear and tensile resistance of 5.2 kN and 2.0 kN respectively [2]. Properties of Sikadur CF 31 using data from the manufacturer of the product with tensile strength in flexure 30-40 MPa at the condition of curing time 7 days and +30°C curing temperature [6].

The stages of making test specimens begin with the preparation of formwork and continuing reinforcement set. The compressive strength of the concrete used was concrete with K250 quality, the composition of the mixture according to Indonesian standard [7]. For concrete quality control also made concrete cylinders and slump value testing [8].

Slab strengthening was completed at the age of the 28-day concrete by giving an additional two CFS of type C75.0.75 with a spacing of 200 mm for each slab in the longitudinal direction. The type C75.0.75 refers to the mild steel profile [9]. The CFS was setting at the bottom of the concrete slab that functions to resistance the pull force. The usage of Epoxy Sikadur CF-31 as glue (SSE) and Dynabolt M10 as a shear connector (SSD) on this object test. A description of test specimens with CFS on the slab can be seen in Figure 2.
During testing, the test object has been placed on a loading frame with the roller and hinge supported at both ends. The dimensions of the slabs are 450 x 1450 x 120 mm and the net span of the slabs was 1350 mm. The load placed in the middle of the span with a distance of 675 mm from each supported. One point loading of flexural test was carried out with a hydraulic jack equipped with a manometer for reading at a load increase interval of 5 kN. The test was carried out until the slab collapses and the load reading indicator touches the maximum load. The settings of specimen loading can be seen in Figure 3.

3. Results and discussion

3.1. Results of material
The results of 10 mm bars steel tensile strength test, obtained yield stress (fy) of 370.22 MPa and ultimate strength (fu) 555 MPa. For cold formed steel yield stress (fy) of 550 MPa and concrete compressive strength (f’c) of 18.45 MPa. This data is used to analyze the capacity of concrete slabs using Whitney Rectangular Stress Distribution on Indonesian Standard [4] and using Response-2000 software for all of slabs.

3.2. Theoretical analysis results
In theoretical analysis, two methods are used, namely the Indonesian standard SNI 2847: 2013 and the Response-2000 software. In the Response-2000 software, half-span modeling and mild steel are
modeled by adding steel extents at the bottom of the slab with yield strength 550 MPa. The results of the analysis can be seen in Table 1. The results have shown that for the two methods used there was only a small difference in value of load. In contrast, deflection shows a significant difference because Response-2000 analyzes non-linear conditions and analyzes crack cross-sections and other non-linear behavior. Increased load capacity is twice as large as CS samples for SSE and SSD specimens with the relatively small deflection.

### Table 1. Theoretical analysis.

| Sample | SNI 2847:2013 | Response-2000 |
|--------|---------------|---------------|
|        | Moment (kN.m) | Load (kN)     | Deflection (mm) | Moment (kN.m) | Load (kN) | Deflection (mm) |
| CS     | 10.67         | 31.62         | 1.24            | 10.53         | 31.2      | 3.8             |
| SSE    | 23.59         | 69.88         | 2.74            | 22.88         | 67.8      | 5.8             |
| SSD    | 23.59         | 69.88         | 2.74            | 22.88         | 67.8      | 5.8             |

3.3. Experimental analysis

The results of the flexural strength test of the control slab and the strengthened slabs with Epoxy as well as Dynabolt can be seen in Table 2. The relationship between load and deflection for the five samples is presented in Figure 4. Table 2 shows that there was an increase in load in the first crack condition, when it reached maximum deflection and load. Increased load capacity can be withstand by strengthened concrete slabs with CFS using Sikadur CF-31 or Dynabolt M10.

### Table 2. Flexural test result.

| Sample | Load (kN) | Moment* (kN.m) | Deflection* (mm) |
|--------|-----------|----------------|-----------------|
|        | First Crack | Limited deflection | Ultimate | Momen* | Deflection* |
| CS     | 10         | 23.8           | 35             | 11.81  | 12.18       |
| SSE-1  | 15         | 36.97          | 50             | 16.88  | 7.56        |
| SSE-2  | 15         | 39.73          | 43             | 14.51  | 6.22        |
| SSD-1  | 16         | 27.49          | 60             | 20.25  | 35.02       |
| SSD-2  | 19         | 24.85          | 59             | 19.91  | 35.31       |

*at maximum load

Figure 4 also shows that the sloping deflection graph in SSD-1 and SSD-2 samples with a higher load capacity compared to SSE-1 and SSE-2. This shows that the use of Dynabolt is able to work better as a shear provider between concrete and CFS compared to the Epoxy Sikadur CF-31. Furthermore, the use of Dynabolt can maximize the ability of CFS to hold out the flexible loads. Evidenced by the shape of the deflection load graph SSD samples almost resemble the CS sample graph.

The increased load on the SSD occurs due combinations CFS with the concrete can be together holds the pull in the tension area. Peak load was reached until failure on the compression side. For SSE specimens, compactness between CFS and concrete slab does not last long because it fails on glue Sikadur CF 31. The failure of this glue was because the shape of the CFS which has flens causes the CFS not only be tensile but also be bouncy and cause the glue to become detached. Apart of that,, SSE still able to withstand a greater load than CS because additional area from CFS contributed against tensile strength.
3.4. Stiffness

Slab stiffness analysis is divided into two parts, the first is called initial stiffness that is the stiffness obtained at the beginning of loading until the first crack (crack stiffness). Next the second is the stiffness obtained at the maximum load. Table 3 shows there was an increase in stiffness in the SSE samples both under first crack and ultimate conditions compared to CS. This occurs because the SSE can carry a greater bending load than the CS samples with smaller deflection (see Figure 4). This shows that strengthening with the use of Epoxy Sikadur can increase the stiffness of strengthened concrete slabs.

Flexible stiffness in the first crack and the ultimate conditions of SSD specimens was smaller than CS sample. In ultimate conditions SSD samples can withstand loads which are almost twice as large as CS but the deflections occur three times greater than CS sample. It means that the use of Dynabolt on slab strengthened cannot increase stiffness particularly after applying large deflections. The above results differ from the reinforcement plates from the results of previous studies made by Frank, et.al. [10] which is 3.5 times increase in load capacity compared with the non-reinforced plate and the deflection occurred was relatively small.

### Table 3. Stiffness of slab.

| Sample | Stiffness (N/mm) |
|--------|-----------------|
|        | First Crack | Ultimit |
| CS     | 5586.59      | 2873.56  |
| SSE-1  | 6521.74      | 6613.76  |
| SSE-2  | 8287.29      | 6913.18  |
| SSD-1  | 6986.90      | 1713.31  |
| SSD-2  | 6129.03      | 1670.91  |

3.5. Comparison of experimental to theoretical results

Table 4 has provided the results of the comparison between the experimental moment (Mu) against the theoretical moment (Mt) and the experimental deflection (δu) against the theoretical deflection (δt) at maximum load. The value of CS sample was different from the moment of theoretical analysis. The moment of the experimental was greater compared the analysis using SNI 2847:2013 and Response-2000, with the differ value of 11% and 12%, respectively. However, the value of this load was reached after the slab has a large deflection, which is indicated by the large value of the deflection ratio that was 9.83 for analysis using SNI 2847:2013 and 3.21 using Response-2000. Moreover, all strengthened slabs have a ratio of less than 1. This means that the capacity obtained during the experiment is smaller than the theoretical analysis. For SSD the difference is not significant and this could be due to the quality of
the concrete that is not homogeneous while the large difference in the SSE occurs because of the failure of the glue of Sikadur CF-31 so that the capacity obtained is not the maximum capacity of the strengthened slab.

| Sample | Mu/Mt SNI 2847:2013 | δu/δt SNI 2847:2013 | Mu/Mt Response-2000 | δu/δt Response-2000 |
|--------|---------------------|----------------------|---------------------|---------------------|
| CS     | 1.11                | 9.83                 | 1.12                | 3.21                |
| SSE-1  | 0.72                | 2.76                 | 0.74                | 1.30                |
| SSE-2  | 0.62                | 2.27                 | 0.63                | 1.07                |
| SSD-1  | 0.86                | 12.97                | 0.88                | 6.04                |
| SSD-2  | 0.84                | 6.12                 | 0.87                |                     |

The failure pattern in the SSE sample can be clear when Sikadur CF-31 which functions as a glue between CFS and the concrete slab begins to detach from the CFS side at maximum load, causing a partial CFS to separate from the concrete slab (see Figure 5). The impact of the load drops dramatically as seen in the load and deflection curve in Figure 4.

**Figure 5. SSE specimen at the testing.**

### 4. Conclusion

- Increased flexural load capacity can be realized by the addition of CFS under the slab with Epoxy Sikadur CF-31 and Dynabolt M10 as a connector.
- Dynabolt can maximize the ability of CFS to withstand flexural loads but cannot increase the stiffness of concrete slabs, particularly after large deflections have occurred.
- The usage of Epoxy Sikadur CF-31 as a glue can enhance the stiffness of the strengthened slabs when compared to the control slab but cannot maximize the ability of cold formed steel as a strengthened material.

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