Experimental study of 90° hook and standard hook at the end of reinforced concrete beam stirrup

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Abstract. Part of shear forces on reinforced concrete structures, will be borne by stirrup. According to Indonesia concrete standard, a closed stirrup must be used in earthquake prone areas. The end of the stirrups should be a hook with an angle ≥ 135°. The focus of this research is the modification of the hook shape on the stirrup reinforcement. This research is expected to design the shape of hook which good performance on shear holding. The basis of this research is experimental testing in the laboratory by cyclic loads. The specimens consisted of 2 pieces: TG1 and TG2. TG1 is a specimen with an angle 135° end-hook shape according to SNI provisions. TG2 is a specimen with an angle 90° end-hook shape. The two specimens are reinforced concrete beams (250mm x 400mm x 1700 mm). From the test, it is proved that the two specimens are collapsed by shear. The ultimate load on the second specimen is greater than the ultimate load of first one, $P_{u1} = 245$ kN and $P_{u2} = 270$ kN. In addition, the deflection of the second specimen is greater than the deflection of the first one, $\delta_1 = 12$ mm and $\delta_2 = 14$ mm.

1. Introduction

In general, there are two types of reinforcement in reinforced concrete beam structures, namely bending reinforcement and shear reinforcement. The vertical stirrup is more often used on reinforced concrete beams. According to Indonesia National Standard, SNI 03-2847-2013 [1], in earthquake-prone areas, a closed stirrup or cross-linker which has a hook (not less than 135°) must be used. As for ring stirrups, it must have a hook of not less than 90°. Indonesia is an earthquake-prone country, at the meeting point of the three largest tectonic plates in the world: The Indo-Australian plate, the Eurasian Plate, and the Pacific plate. Until now there has been no technology that can predict the time, place, and intensity of an earthquake. Several approaches have emerged to anticipate earthquakes so as not to cause major damage.

First, the design process must follow the rules required in earthquake regulations [2]. Second, a building is required to always follow the rules of correct reinforcement. The shear reinforcement must have a 135° hook at the end. In reality, the 135° end-hook on shear reinforcement of reinforced concrete beams is almost never done. Generally, constructions use a 90° end-hook. This research is expected to find the shape of the end-hook of the shear reinforcement which, besides being easily applied in the construction, also has the same or stronger than 135° end-hook shear reinforcement.

The study of shear reinforcement has been carried out by several researchers. A study of shear reinforcement which used welding at the meeting of both ends of the reinforcement has been conducted, and the result of this study shows that the stirrup welded in the corner can resist the highest shear force with a value of shear force $(Vu) = 203,681$ kN, maximum load $(P) = 406,593$ kN, and shear strength
contributed by reinforcing steel (Vs) of 159,913 kN [3].

Basuki, et al. examined whether or not the existence of a cross-section in a horizontal direction [4]. If there is no need, this is material and cost-efficiency. This stirrup is called an alternative stirrup. The results of this study indicate a difference in shear strength between conventional stirrup reinforcement and alternative stirrup reinforcement. Although there are differences in values, it is generally said that the shear strength between conventional stirrups and alternative stirrups is relatively the same.

Igbal et al conducted a study of conventional shear reinforcement [5]. This study was conducted to determine the shear behavior between vertical stirrups with 135°, 90° end-hook angles and "U" vertical stirrup models in reinforced concrete beam construction. The results showed that the vertical stirrup with an angle of 135° end-hook was stronger than the 90° end-hook and the vertical stirrup of the "U" model. Similar research has also been carried out by Basuki [6]. The purpose of this study was to compare variations end-hook angles of the vertical shear reinforcement of the SNI 03-2847-2013 [1] model (135° angle) and the market model (90° angle) to the shear strength of reinforced concrete beams. The results of this study indicate that the vertical shear strength of the SNI model is greater than the vertical stirrup (which commonly used) strength. The difference in shear strength between the two types of reinforcement is also quite significant, which ranges from 16.82% - 81.41%.

In addition to this research, it refers to several research results and SNI - 03 - 2847 – 2013 [1], regulations, also considering conditions in the field. In accordance with SNI - 03 - 2847 – 2013 [1] for end-hooks in earthquake-prone areas, a closed stirrup must be used, which has end-hook not less than 135°. However, during construction, on average 90° end-hooks are used as revealed by Basuki [6]. This is confirmed by the research of Igbal et al [5], indicating the use of 90° end-hooks on stirrups without modification should be avoided.

Full scaled test results in the laboratory are needed to prove theoretical calculations. Theoretical calculations will be considered good if it is close enough to the results of testing in the laboratory. This is in accordance with what Pavlo et al said that the deviation between theoretical calculation by the proposed empirical formula and experimental data is 10% which provides sufficient reliability of the results for future using [7]. Research on shear behavior of high-quality stirrups has also been carried out by Lee et al [8]. One interesting conclusion is about the width of the crack. The crack width at different load levels of all the tested beams was nearly constant, regardless of fyt. The experimental results showed that the maximum crack width of the simply supported beam with relatively greater fyt is approximately the same as (or a little narrower than) that of the beam with lower fyt.

Several studies have succeeded in increasing structural ductility. One of them is a study conducted by Kamil et al on the column-beam connection [9]. The studies made clear that using steel fibers will increase ductility, stiffness and toughness in concrete. There are many studies to increase shear strength. Munikrishna et al conclude that the shear strength of flexural members can be achieved by using a lesser amount of high-strength stirrups and more alow high-strength longitudinal reinforcement ratio in comparison with using Grade 60 reinforcement [10]. Arun et al conducted a study on the effect of shear reinforcement on T-beams [11]. This research yields the conclusion that in the case of T-beams without shear reinforcement, however, the width of flange has almost no effect on the shear capacity.

Zakaria et al who conducted an experimental investigation on shear cracking concluded that shear cracks width increases proportionally with both the strain of shear reinforcement and with the spacing between shear cracks [12].

In his study of seismic performance of reinforced concrete columns for shear reinforcement, Hakuto concluded that the test units with deformed bars for the longitudinal reinforcement failed in shear after the flexural strengths were reached while those with plain round bars did not show shear failure up to the end of testing [13].

In the past, the Smeared approach was used to identify the cracks in RC beam using ANSYS but in this work, it was extended using a discrete approach of modeling and shear cracks were identified in RC beam and load-deflection curve was simulated which showed good agreement with the experimental results [14]. Khan et al used ANSYS to identify shear cracks in the reinforced concrete beam [15]. They concluded that the initial cracking load is the same for both finite element and experimental beam.
This research is focused on the shape of the shear reinforcement end-hook where at the meeting the two ends are bound with wire. The hope, in order to obtain the right hook and bond shape so that it is easily applied during the construction.

2. Methods
The research steps can be seen in Figure 1 as follows.

![Figure 1. Research steps.](image)

The shape of the standard end-hook shear according to SNI 03-2847-2013 [1], can be seen in Figure 2a. The shape of the 90° end-hook (tied by wire on both ends) is shown in Figure 2b.

![Figure 2. Shape of shear reinforcement end-hook.](image)

The specimens are a simple beam of reinforced concrete with dimensions of 250 mm x 400 mm x 1700 mm. These simple beams are tested by cyclic loading.
3. Results
From the tensile test results obtained $f_y = 381.6$ MPa for steel 16mm diameter. Whereas in the 6 mm diameter steel, the value of $f_y = 542.4$ MPa was obtained. Concrete compressive strength testing of 3 (three) 150 x 300 mm cylindrical specimens obtained $f_c' = 31.6$ MPa

3.1. Testing of reinforced concrete beams of TG 1 specimens
Tests with cyclic loads on TG-1 type beams using displacement control: 1 mm, 2 mm, 4 mm, 8 mm, and 16 mm. From the results of tests on the TG-1 beam type, the load-deflection relationship as shown in Figure-3, and the crack patterns that occur as shown in Figure 4.

![Figure 3. Relationship between load and deflection of TG-1.](image)

![Figure 4. Crack patterns of TG-1.](image)

Figure 3 shows that the collapse occurred at a load of 245 kN during the 5th cycle, at deflection = 12 mm. Crack patterns that occur due to cyclic loading, as shown in Figure 4. In the picture it appears that the shape of the cracks on the crossing beams. In addition, the picture also shows that the collapse that occurs in the beam is a sliding collapse. This is indicated by the existence of diagonal cracks and the appearance of gaps in the beam. This collapse is still classified as brittle collapse with limited warning.

3.2. Testing of reinforced concrete beams of TG-2 specimens
The cyclic load testing of the TG-2 beam is carried out using the same method as the TG-1 beam. The results of the TG-2 beam testing on the relationship between the load and deflection Figure 5. The crack pattern that occurs can be seen in Figure 6.
Figure 5. Relationship between load and deflection of TG-2.

Figure 6. Crack patterns of TG-2.

Figure 5 shows that the loading process that caused the beam to collapse occurred at a load of 270 kN. This occurs in the 5th cycle, which is at deflection = 14 mm. The crack pattern that occurs as a result of this cyclic loading can be seen in Figure 6. The figure shows the existence of cross-cracking shapes. The collapse is a type of shear failure. This is indicated by the diagonal crack and the separation (gap) on the beam. This collapse is still classified as brittle collapse with limited warning.

4. Discussion
The shear bar diameter of 6 mm has yield stress, $f_y = 542.4$ MPa. Thus, the initial calculation of shear reinforcement must be changed to adjust the results of this test. The distance between stirrups which was originally 80 cm was changed to 150 cm. The beam crack pattern in Figure 4 and Figure 6 show that the beam designed has shear collapse. This is in accordance with what was originally planned. The results of beam testing using cyclic loading can be seen in Table 1.
Table 1. Results of beams testing with cyclic loading.

| No. | Specimen | Types of failure | Load Pu (kN) | Deflection (mm) |
|-----|----------|------------------|--------------|-----------------|
| 1   | TG-1     | shear            | 245          | 12              |
| 2   | TG-2     | shear            | 270          | 14              |

5. Conclusions
The results of beam testing by cyclic loading get the same failure pattern that is shear failure. The magnitude of the collapse load and deflection that occurs is as follows. For TG-1 beams, the Pu load collapses = 245 kN, and deflection = 12 mm. Whereas in the TG-2 beam, the load collapsed Pu = 270 kN, and deflection = 14 mm

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