Stress-strain behaviour of steel bars with long nut connection

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Abstract. The reinforcement of reinforced concrete always needs a connector. In order to reduce the overlapping length, the long nuts are used as steel bar connector. The tensile experimental test was obtained to find out the value of yield stress, ultimate tensile strength, elongation and ductility which can be achieved by steel bar long nut connection. The test was using UTM machine instrument which connected to the computer, thus stress-strain curve is obtained. The curve shows the values of elastic, plastic, strain hardening until ultimate tensile strength region, value of yield stress $F_y$, and ultimate tensile strength $F_u$. The result of tensile tests how’s that the yield stress value of steel bar with long nut connection has the same value with the steel bar without connection. The steel bars with long nut connection can achieve yield stress about 330 MPa, ultimate tensile strength about 340 MPa and strain value about 5%-6%, it is lower than the steel bars without connection. It indicates that long nut can be used as a connector tool in overlapping steel bar connection.

1. Introduction

Steel bars are used for reinforcement on beams, columns, or slab of reinforced concrete construction and it is always requiring a connection. It is because the steel bar length is not long enough in structural element. In general, the length of one steel bar is available in 8 or 12 meters. Therefore, a connector is required and the reinforcement that is installed should be overlapping. According to SNI 2847:2013, overlapping length is not less than 300 mm. At the end of steel bar is blended with 135° angle as a hook [1]. The hook for tie stirrups needs additional steel bar length are $4d_b$ for 10 mm to 25 mm (deform) on diameter [1]. Therefore, there are overlapping installment and hooks in the steel bar in order to create additional length reinforcement.

Regarding to that, the assembling technique of overlapping can be simplified by using connect or to gather the reinforcing edge of one and another without bending, thus the length of overlapping reinforcement can be reduced. The connecting tool that will be use should be feasible to install, it does not need a large space to move and not require the hand work of the workers to install, and has a strong ability to hold both of the ends of the steel bar.

The reinforcement connection overlap includes parts of structural reinforcement detailing which is very essential, thus it is not easily dislodged when the structure experiences shaking due to an earthquake, especially buildings that built in high seismic risk areas.
2. Literature review

2.1. Stress-strain curve

The tensile experimental test was conducted to determine the performance capability of steel bar with long nut connecting tool to resist the force. In other words, determining how much the maximum tensile load that is able to resist, the yield stress value \( F_y \), the ultimate tensile strength \( F_u \) and strain value or elongation \( e \).

The stress-strain curve from the result of tensile experimental test shows in Figure 1 [2]. The ordinate shows the stress value \( f \), and the abscissa is strain value \( \varepsilon \). Curve shows that from zero until proportional limit is linear, regarding the Hooke’s law. Then, the peak value at the upper yield point is reached immediately, followed by a leveling off at the lower yield point. The stress from zero until upper yield point is called the elastic region, where the steel is still in elastic condition. At this stress, the loading can be removed without permanent deformation on steel material. In Figure 1, the elastic limit unloading is along a straight line parallel to the initial linear part of the loading path, and the strain is permanent. For example, if the load is removed at point \( A \), then the unloading line is along \( AB \) line, resulting in the permanent strain \( OB \).

![Stress strain curve of steel bar tensile experimental testing result.](image)

**Figure 1.** Stress strain curve of steel bar tensile experimental testing result.

After lower yield point, the stress remains constant, but strain continues to increased. At this stage of loading, the test specimen continues to elongate as long as the load is not removed, even though the load cannot be increased. The constant stress region is called plastic range. When the strain is approximately 12 times the strain at yield condition, strain hardening condition begins, and additional load (and stress) is required to cause additional elongation (and strain). A maximum value of stress is reached, after which the specimen begins to “neck down” as the stress decreases with increasing strain, and finally fracture occurs.

According to Segui [2], ductility can be measured by the elongation value,

\[
e = \frac{L_f - L_0}{L_0} \times 100
\]

with:
- \( e \) = elongation (on %)
- \( L_f \) = length of the specimen at fracture
- \( L_0 \) = initial length of specimen
Figure 2 shows an idealized version of stress strain curve [2]. Proportional limit, elastic limit, upper dan lower yield point are all close to one another and treated as a single point called the yield point, defined by the stress $F_y$. The maximum value of stress is called ultimate tensile strength $F_u$ which is a very essential point that is required by the structural engineers. The value of yield stress $F_y$ and fracture stress $F_u$ are used as a strength reference of steel material. The $E$ value is Young’s modulus or modulus of elasticity obtained from the ratio of stress to strain in the elastic region, $E = \frac{f}{\varepsilon}$. While in Indonesia, the standard SNI 03-1729-2002 [3], determining $E$ value is 200,000 MPa.

![Figure 2. Idealize of stress strain curve.](image)

Figure 3. (a) The modified long nut and steel bars, (b) The long nut connector mounted on the steel bars.

3. Research method

3.1. Long nut
The long nut used at testing was made by steel material (Figure 3a and 3b), the strength is ST42, and the length is 20mm. The long nut has a specific modifier thread direction, which has different thread direction as shown in Figure 4. The thread was made at the ends of steel bar to enter at the long nut (Figure 3a), then the long nut is rotated in one direction until the ends of the steel bars enter the long nut, and it is connected (Figure 3b).

3.2. Steel bar specimens
The strength of steel bar specimens uses BJ 37. According SNI 03-1729-2002 [3], its yield stress is $F_y$ 240 MPa and ultimate strength tensile or fracture stress is $F_u$ 370 MPa. The diameter of steel bars is 8mm and not deformed. One specimen consists of 2 (two) steel bars with the length of each is 300mm (Figure 5). This length is adjusted to the space of the tensile strength test machine. In order the steel bar is able to enter the long nut, at one end of the steel bars are given thread in the direction of the slope according to the long nut thread direction.
There are two types of specimens, one is steel bar with long nut connection (A-01 Long nut, A-02 Long nut dan A-03 Long nut types) as shown in Figure 6, and steel bar (type A-01, A-02 and A-03 types) as shown in Figure 7 as a comparison parameter.

**Figure 4.** Thread design of modified long nut.

**Figure 5.** Steel bar specimens will be connected using long nut.

**Figure 6.** Steel bar specimens have connected on the long nut.

**Figure 7.** Steel bar specimens without long nut connection.

3.3. **Steel bar tensile strength experimental testing**

The instrument of tensile strength that is used Universal Testing Machine (UTM) which the specimens can subjected to axial load, and the instrument is connected to computer (Figure 8), therefore the stress and strain values in the curve form can be determined directly. The speed of tensile strength test refers to ASTM A370-05 [4]. Steel bar specimens are subjected by tensile axial load $P$ (Figure 9) that are given
gradually until fractured. Before tensile test is done, steel bars are given mark along 200mm and the long nut in the test area, this aim to determine the length of the object when fracture (\(L_f\)), thus the value of elongation \(e\) can be defined. In addition, it aimed to determine whether the long nut connection will cause weakening of the steel bar. It is expected that the damage will not occur in the long nut connection.

**Figure 8.** Instrument of steel bar tensile testing.  
**Figure 9.** Long nut in the testing area.

4. Discussion

4.1. Tensile strength testing result of steel bar

The result of tensile strength test as in Table 1, it is indicated that the stress and strain values are in yield condition (\(F_y\) dan \(\varepsilon_y\)), maximum value (\(F_m\) dan \(\varepsilon_m\)), and strength ultimate (\(F_u\) dan \(\varepsilon_u\)) of the each of specimen. The yield stress \(F_y\) of both steel bar with or without long nut connection reach stress value which the difference is not significant, about 329 to 340 MPa. The yield stress is not affected by long nut connection, all steel bar reach yield stress according to the strength specified by steel bar manufacturer, that is 320 MPa.

The modulus of elasticity \(E_s\) obtained from ratio between stress value to strain of steel bar with long nut connection is in average 397,000 MPa, it is higher about 2% than steel bar without long nut connection is in average 200,000 MPa. This shows that there is a connection with long nut connector at steel bar will cause elasticity of steel bar to decrease, and become more rigid. Elongation is occurred at steel bars without long nut connection reach 20% to 22%, while steel bar with long nut connection reached average 5% to 6%, it is around 20% lower than the steel bar without long nut connection. The steel bar with long nut connection is more rigid and its elongation lower than the steel bar without long nut connection. This problem occurs because when steel bar is subjected to axial tensile load, in the connecting region, elongation of deformation at the steel bar appears to reduce the area of steel bar.
Table 1. The result of steel bar with and without long nut connection tensile testing.

| Specimen | Steel Diameter (mm) | Yield Stress | Maximum | Ultimate | Es (MPa) | Elongation (%) | Ductility |
|----------|---------------------|--------------|---------|----------|----------|---------------|-----------|
|          | fy (MPa) | ey (MPa) | fmax (MPa) | em (MPa) | fu (MPa) | em (MPa) | g/ey | g/y |
| A-01     | 8    | 337.05 | 0.00540 | 448.29 | 0.1869 | 331.81 | 0.2245 | 198723.94 | 22.45 | 34.611 | 41.574 |
| A-02     | 8    | 335.32 | 0.00280 | 454.36 | 0.1818 | 389.05 | 0.2005 | 208088.23 | 20.05 | 64.929 | 71.607 |
| A-03     | 8    | 340.87 | 0.00132 | 462.67 | 0.1998 | 417.76 | 0.2260 | 263269.78 | 22.60 | 151.36 | 171.21 |
| Average  |       | 337.75 | 0.00317 | 455.11 | 0.1895 | 379.54 |         | 223600.65 |

| A-01 Longnut | 8    | 329.03 | 0.00104 | 381.44 | 0.0290 | 348.37 | 0.0321 | 390974.83 | 6.05 | 27.885 |
| A-02 Longnut | 8    | 335.60 | 0.00119 | 390.25 | 0.0297 | 335.65 | 0.0325 | 398133.56 | 5.85 | 24.958 |
| A-03 Longnut | 8    | 337.42 | 0.00130 | 394.67 | 0.0334 | 354.33 | 0.0357 | 402757.53 | 6.10 | 25.692 |
| Average    |       | 334.02 | 0.00118 | 388.79 | 0.0307 | 346.12 |         | 397288.64 |

Figure 10. Stress strain curve of steel bar without long nut connector.

4.2. Stress strain curve

The steel bar stress strain curve of tensile test result are obtained from the output of computer as shown in Figure 10 is curve of the steel bar without long nut connection, Figure 11 is the curve that represents the steel bar with long nut connection curve, and Figure 12 is curve that represents of all the steel bar specimens. From the diagram, it is obtained that steel bar with long nut connection reached yield stress
Fy around 330 MPa, and that value is not different with Fy of steel bar without long nut connection. After Fy is reached, the elongation that occurred at steel bar with long nut connection is lower than steel bar without connection. Finally, the ultimate tensile strength Fu is obtained from fracture value, at steel bar with long nut connection reach about 340 MPa, it is lower about 14% than steel bar without connection which reach Fu about 380 MPa.

Figure 11. Stress strain curve of steel bar long nut connector.

The elongation of steel bar without connection is obtained about 20% to 22%, that is according to SNI 03-1729-2002 that steel bar elongation is about 22% [3]. The elongation of steel bar with long nut connection is obtained about 5% to 6%. Initially, in elastic condition, the elongation of steel bar with or without long nut connection are same. At plastic condition, which is after elastic condition, strain value of steel bar with long nut connection is lower that steel bar without connection. This shows that the steel ability to receive axial tensile force is not influenced by long nut connecting, but the effect on the elongation get out lower about 20% than the steel bar without connection. The steel bar with long nut connection still has an elongation ability when it is subjected axial tensile load, although its ability is not as large as steel bar without connection. This condition indicates that steel bar with long nut connection can be used for the structural reinforcements, if needed connection using long nuts are not install at part of structural which withstand axial tensile forces.

Figure 12 shows stress strain curve of all steel bar specimens, both steel bars with or without long nut connection. In elastic region, where condition of steel bar without loading to yield point there is no significant difference in values, both steel bar with or without long nut connection. In this elastic condition, the modulus of elasticity value can be determined, and result is obtained that modulus of elasticity of steel bar with long nut connection higher than steel bar without connection. As it is anticipated, the fracture damage is not occurred at connection tool but at steel bar. From that result indicates that steel bar with long nut connection still has the ability to receive the same load as steel bar without connection, but the elasticities decreases. This explain that the overlapping of steel bar
connection in building construction can be used connecting tool long nut, but the force direction is not aligning with the long nut.

![Stress strain curve of steel bar specimens.](image)

**Figure 12.** Stress strain curve of steel bar specimens.

The ductility of steel bar is obtained from the value of stress strain curve (Figure 12) which is define with two method, the first based on ratio between the maximum tensile strain $\varepsilon_m$ to yield strain $\varepsilon_y$, and the second based on ratio between ultimate tensile strain $\varepsilon_u$ to yield strain $\varepsilon_y$ as show in Table 1. The maximum ductility of steel bar long nut connection is obtained 30, and steel bar without connection is 85, that different value is about 65%. The ductility ultimate of steel bar with long nut connection is obtained 28, without connection is 95, about 71% different value. The ductility of steel bar long nut connection reaches lower than steel bar without connection, caused there is influence of elongation. The elongation at steel bar long nut connection was halted in threat due to the surface of steel bar in threat region is reduced.

The fracture at steel bar specimens occur in testing area of 200mm, that is as specified in the SNI 03-1729-2002 [3]. Figure 12 shows the fracture occurs at steel bar without connection, and steel bar with long nut connection as show in Figure 14.

At the steel bar with long nut connection, fracture occurs in the threat area, close with long nut connecting (Figure 14). This can be occurred due to when the tensile load is subjected, the elongation occurs in steel bar and stops at the thread because the surface area of the thread area is smaller than the surface area of the steel bar which is not threaded. Fracture occurs in the steel bar area, not in the connection device. It is as expected that the long nut connecting device has the strength to withstand axial tensile forces and it has no fractured.
Figure 13. Fracture condition of steel bar without long nut connection specimens after tensile test.

Figure 14. Fracture condition of steel bar long nut connection specimens after tensile test.

5. Conclusion
From the discussion, it can be concluded that:

- From the stress strain curve, it is obtained that in elastic condition, the yield stress value $F_y$ of a steel bar with and without long nut connection has achieved slightly similar value. In the ultimate tensile strength, it is obtained that from the fracture stress $F_u$, steel bar with long nut connection reached the $F_u$ 14% lower than the steel bar without connection.
- Steel bar with long nut connection has the elongation ability around 5%-6%, and it has no fracture in the connector. However, it appears in the steel bar. This indicates that the long nut connector can be used as an overlap connector of a steel bar for a structural that has no resistance of tensile strength that is in the same direction with the long nut.
- Ductility steel bar with long nut connection is 71% lower than the steel bar with no connector. Ductility steel bar is affected more in its elongation.

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