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A Proposed Clamp System for Mechanical Connection of Reinforcing Steel Bars

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Abstract
The city development in Indonesia is more oriented to the overground space and this is because the urban population has increased significantly and it is incomparable with the land available in the cities. The number of high-rise buildings and skyscrapers also marks this phenomenon. However, high-rise buildings and skyscrapers have the potential to be vulnerable to the earthquake hazard in Indonesia particularly those located at the high risk seismic regions. In the design of seismic resistant buildings, there are two important aspects required to be considered, namely strength and ductility. The deformation capability and better innovative reinforcement connection become primary consideration in the design of seismic resistant structures. From the tensile tests of reinforcing steel bars with clamps, it is shown that D13 bars has the yield and ultimate tensile strengths of 270.69 and 351.45 MPa, respectively, with the maximum load of 4,757 kg and the maximum elongation of 40%. As for the D16 bars, the yield and ultimate tensile strengths of 217.80 and 327 605 MPa, respectively, with the maximum load of 6,717 kg and the elongation of 32%. In the study, two pieces of steel clamps were tested, it is found that to obtain better results there is a need to increase the number and improve the quality of material of the steel clamps.

Keywords: Ductility, Mechanical Connections, Overground Space, Strength, Steel Clamp.

INTRODUCTION

Management of urban planning that are comfortable, healthy, and environmentally sound is currently a trend in Indonesia. This is supported by the governmental policies which require the green open space up to 30% of the total area of the city. Both the government and community have now realized that the environmentally friendly cities has become a necessity for today's and the future.

The urban population have been increasing in all provinces in Indonesia. With the growth of urban population exceeded the capacity of the land, it will result in a vertical urban growth (uper ground). Whether in the form of growth upwards (overground space) or downward (underground space). Indonesia's current urban growth is more oriented to the overground space, as is evident with the emergence of many high-rise buildings and skyscrapers. However, due to the lack of planning and design of building structure overground spaces, it will be highly vulnerable to seismic hazard. This is because most parts of Indonesia are in the path of tectonic plates of Eurasian, Pacific and Indo-Australian and the circumstance path of "Pacific-rims: ring of fire" that outlines the potential for volcanic catastrophic. The most recent Indonesian seismic map has also accommodate the impact of earthquakes on buildings with the increase in seismicity of the seismic loads.

Two important things to consider when designing the building structures are the strength and ductility [1-5]. Strength and ductility of the structures should be sufficient to transfer the forces from a structural component to another during the earthquake [6-9]. The strength of the structures is governed by the increase of load due to the earthquake load which could exceed the design load [10-15]. Ductility is associated with the resistance of the struc ture to prevent a sudden collapse (brittle failure) due to earthquake load [16-21].

Column plays an important role in a building structure, considered that the failure of the column will result in failure (collapse) the overall structure [22-26]. On the other hand, the columns are the structural members that are vulnerable to failure when it resists the seismic load. In addition, the beam-column joint is the part of structures that needs special attention when it resists seismic load. Thus, a study on columns and beam-column joints is needed particularly when it resists the seismic load [27-30].

This research focuses on the performance of a reliable reinforcing bar connection through the study by reviewing deformation capability (ductility or performance) connection and reinforcement elements as well as the strength. To ensure the capability of the reinforcing bar connection, the tensile tests, in accordance with the applicable standards, were conducted to demonstrate the performance and adequate strength when compared with the continuous reinforcement without any connection and they are expected to perform comparable or even better, if possible.

The deformation capability and the strength that are better for the innovative reinforcing bar connection are considered in designing the structures, especially when the structures experience the increased of loading due to the earthquake. Basically, all materials will deform under the given load. Physically, these changes can be either the elastic or plastic deformation, small or large. Materials that can withstand a large plastic deformation is considered to be ductile. Ductile material is capable of absorbing large amounts of energy before failure occurred where the material is capable of large deforming before failure. To satisfy the needs of the ductility, most of the steel bar specimens were connected with the innovative bar connections and compared with the continuous reinforcement without any connection. If the performance and strength is better or at least equivalent, then this will be a breakthrough very influential in the world, especially the construction planning is not just in the country and even abroad.

The limitation in length of reinforcing steel bars from the mill has caused the steel reinforcement required to be connected since the needs of longer length in the site that than those can be produced by the steel manufacturer. The connection becomes important since it serves to transfer the forces and behaves as transmitter to dissipate the energy between the connected components [31]. The location and the strength of the connection needs to be well designed so that its presence does not cause premature collapse of the structures [32].

Splicing of reinforcement can be done in three ways, namely lap splice, welded joints (welded splice), and mechanical connections [33]. Based on SNI 2847:2013 [34] Section 12.14.3.1 states that the mechanical and welded connections are permitted. A mechanical connection must be able to develop the tensile or compressive strength as required, at least 1.25fy of reinforcing bars (Section 12.14.3.2) and if it does not satisfy the required 1.25fy then it can only be used for connecting D16 bars or smaller with a requirement that it should satisfy Section 12.15.5 of the code.

The mechanical connections according to ACI 439.3R-91 [31] are divided into three basic categories, namely: 1) Compression only Mechanical Connections; 2) Tension only Mechanical Connections, and 3). Tension-Compression Mechanical Connections. Compression only Mechanical Connections have compressive stress transfer mechanism from one end to another end reinforcing bars connected in a single line of axis (concentric). There are several types of Compression only Mechanical Connections, e.g. Solid-Type Steel Sleeve Coupling, Strap-Type Steel Sleeve Coupling, Steel-Filled Coupling Sleeve, and Wedge-Locking Coupling Sleeve. Figures 1 to 4 show the types of Compression only Mechanical Connections.

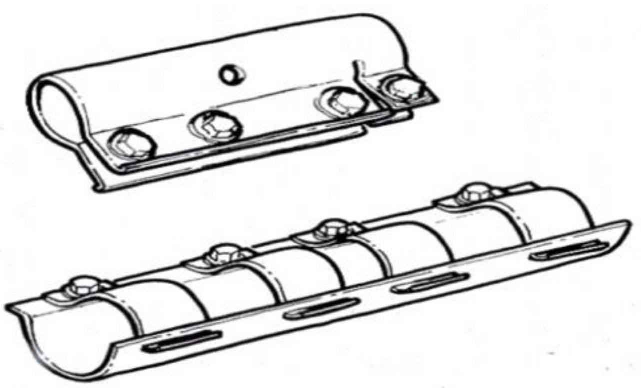

Figure 1: Solid-Type Steel Coupling Sleeve

Figure 2: Strap-Type Steel Coupling Sleeve

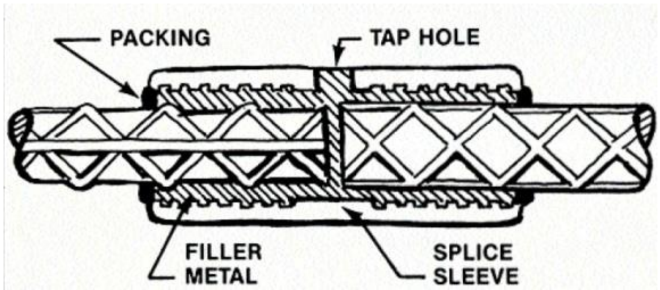

Figure 3: Steel-Filled Coupling Sleeve

Figure 4: Wedge-Locking Coupling Sleeve

Tension only Mechanical Connections are used in circumstances where reinforcement only experiences tensile stresses like flexural reinforcement, expansion shrinkage reinforcement. Tension only Mechanical Connection type includes: Steel Coupling Sleeve with Wedge and Double Barrel Bar Splice. Figures 5 and 6 show the type of Tension only Mechanical Connections.

Figure 5: Steel Coupling Sleeve with Wedge

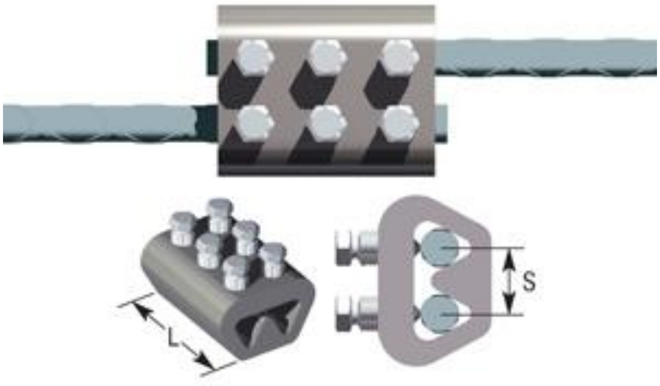

Figure 6: Bar Splice Double Barrel

This type of connection can develop 125% of the yield stress of the reinforcing steel connected. It can be used to connect different diameter reinforcing steel.

Tension-Compression Mechanical Connections has a combined function of tension and compression. The connection types include: Cold-swaged Coupling Steel Sleeve and Taper-Threaded Steel Coupler. Figures 7 and 8 show the type of Tension Compression Mechanical Connections.

Figure 7: Cold-Swaged Steel Coupling Sleeve

Figure 8: Steel Coupling Sleeve

EXPERIMENTAL PROGRAM

The innovative reinforcing bar clamp connection specimens fabricated in the study try to accommodate the deformability and bond strength when compared with continuous reinforcement without any connection through tensile testing in accordance with the code. This study utilizes the innovative technology on reinforcement connection that can be used in reinforced concrete structural elements and thus, eventually it can replace the function of lap splice or seismic hooks which have brought many issues on the performance and strength that do not satisfy with that is expected in the design. The ease of implementation is also one of the concerns where the seismic hooks will greatly interfere with the casting of concrete due to the reinforcement congestion so that the quality of the concrete will drop and it also cannot satisfy the quality specified in the specification of which the concrete can defect (honeycomb) which is easily found today in the construction site during concreting.

Specifications clamp steel specimens:

The material used in this study is 15 mm thick steel plate with fy = 250 MPa and shaped into clamps. Steel Clamp Types 1a and 1b (CT-CT-1a and 1b) will be used into mechanical connections to join deformed reinforcement of D13 and D16 which have fy = 350 MPa. The mechanical connections of Steel Clamp Types 1a (CT-1a) and 1b (CT-1b) can be seen in Figs. 9 and 10.

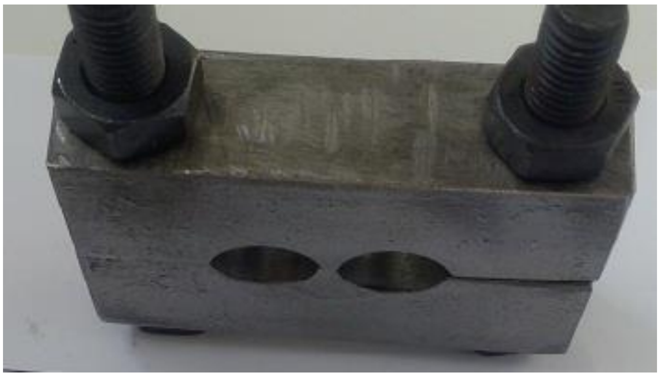

Figure 9: CT-1a

Figure 10: CT-1b

Nuts and Bolts:

The bolts used in the test are of high quality that meets the standards of DIN/EN-ISO (DIN standard that has been adopted by ISO) Grade 8.8 and Size M10. Grade 8.8 has a minimum tensile strength of 800 N/mm2 or equal to 116 ksi (116.030 lbf/in2) with a proof stress of 640 N/mm2 and hardness of 22-32 HRC. The elongation after fracture of minimum 12%.

Figure 11: Nuts and Bolts

Reinforcing Steel:
The reinforcing steel used in the test was deformed steel with Grade U40 and diameters of 13 mm (D13) and 16 mm (D16). The reinforcing steel was produced from raw materials by means of hot rolling process (SNI-07-2052-2002). The deformed reinforcing steel bars must have regular fins. Each rod is allowed to have two longitudinal ribs parallel to the longitudinal axis of the rod and fins transverse to the longitudinal axis of the rod. The fins transversely formed along the the reinforcing steel rods and located at regular intervals with the same shape and size. Transverse fins must not form an angle of less than 45° to the longitudinal axis of the rod. If the angle is between 45 and 75°, the direction of transverse fins on one or both sides are made in opposite direction. The reinforcing bar specimens which have been connected with the mechanical connection of two steel clamps were tested in direct tension. Figures 12 and 13 show application of the mechanical device of steel clamps on the steel reinforcement.

Figure 12: Installation of CT-1a on reinforcement D13

Figure 13: Installation of CT-1b on reinforcement D16

Test Setup:
The tensile tests were carried out on the reinforcing steel bars without and with the mechanical connections of steel clamps. The tensile tests were intended to obtain the data, such as the yield strength, the maximum tensile stress (ultimate tensile strength), the maximum load (maximum force), and the elongation. The test setup is shown in Figure 14.

Figure 14: Test Setup

RESULTS AND DISCUSSIONS
From the test of reinforcing steel bars of D13 without steel clamp, the average yield stress (yield strength) was found to be 391.59 MPa with the maximum tensile stress (ultimate tensile strength) of 595.81, maximum tensile force of 8,064.67 kg and the maximum elongation of 24%; whereas for the D16 reinforcing bars, the yield stress (yield strength) was found to be 394.96 MPa with the maximum tensile stress (ultimate tensile strength) of 585.24 MPa and the maximum tensile force of 12,000 kg and the maximum elongation of 24%.
The tensile test of D13 reinforcing steel bars with mechanical connection of 2 (two) pieces of steel clamps CT-1a has given the yield stress (yield strength) of 270.69 MPa, the maximum tensile stress (the ultimate tensile strength) of 351.45 MPa, the maximum tensile force of 4,757 kg, and the maximum elongation of 40%; whereas the tensile test of D16 reinforcing bars with the mechanical connection of 2 (two) steel clamps CT-1b has given the yield stress (yield strength) of 217.80 MPa, the maximum tensile stress (ultimate tensile strength) of 327. 60 MPa, the maximum tensile force of 6,717 kg, and the maximum elongation of 32%. In testing of specimens with connections, the output readings of the elongation of the specimens generated by the apparatus were in low accuracy.

Table 1: Comparison of test results.

No.	Specimen	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Maximum Tensile Force (kg)	Elonga-tion (%)
1	D13 (without clamp)	391.59	595.81	8064.67	24
2	D13 (with clamp)	270.69	351.45	4757	40
3	D16 (without clamp)	394.96	585.24	12000	24
4	D16 (with clamp)	217.80	327.605	6717	32

From the data in Table 1 it can be concluded that the percentage of success of the steel clamp connections as many as two (2) pieces for the D13 bars has achieved about 69.125% of the yield stress of the steel bars, the maximum tensile stress of 58.98%, and 58.98% of the maximum tensile force from the desired target that is the reinforcing steel yields and subsequently ruptured prior to the clamp failure. The percentage of success for steel clamps of D16 reinforcing bars was about 55.14% of the yield stress, the maximum tensile stress of 55.98%, and 55.98% of the maximum tensile force from the same target w ith the D13.

The damage pattern of the steel clamps was characterized by the damage of the steel clamp surfaces in direct contact with the deformed reinforcing steel bars. The damage in the form of surface failure was followed by the buckling of the bolts and steel reinforcement. Figure 15 shows the damage pattern of the steel clamp.

Figure 15: Damage patterns of the steel clamp

CONCLUSION

The results of tensile reinforcement tests with mechanical connections of steel clamps CT-1a on D13 reinforcing steel bars have given the yield stress (yield strength) of 270.69 MPa, the maximum tensile stress (ultimate tensile strength) of 351.45 MPa, the maximum tensile force of 4,757 kg, and the maximum elongation of 40%. For steel Clamp CT-1b test with D16 reinforcing bars has also given the yield stress (yield strength) of 217.80 MPa, the maximum tensile stress (ultimate tensile strength) of 327.605 MPa, the maximum tensile force of 6,717 kg, and the maximum elongation of 32%.

The performance of the steel clamp CT-1a can be represented through the following results, namely the maximum stress reached 69.125% of the yield stress, 58.98% of the maximum tensile stress, and 58.98% of the maximum tensile force from the desired target. The steel clamp CT-1b attained up to 55.14% of the yield stress, 55.98% of the maximum tensile stress, and 55.98% of the maximum tensile force from the desired target. In the next phase of the work, the mechanical connections are required to be enhanced in terms of the number and the quality of the steel clamps.

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