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EXTENDED ABSTRACT

Analytical modeling of rehabilitated beam-column connections with non-seismic details using joint enlargement and post-tensioned

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1. Introduction

The inability of beam-column joints to play their key role in the seismic resistant system of the flexural frame is a subject that continues to be reported in significant damages and the threat of collapse of reinforced concrete buildings in recent earthquakes. Common operational violations and design of reinforced concrete buildings based on old regulations, which were mainly based on gravity approaches, have caused non-seismic details for the beam-column connection area to be observed in many existing structures (Paulay et al., 1992, Engindeniz et al., 2005, Kaya et al., 2019). The operational and cost-effective improvement technique by enlarging the connection area is one of the rare methods that, in addition to reviving the function of the connection prone to seismic damage and ensuring the formation of a stable plastic joint in the bending beam, it is completely architectable and able to achieve the desired effects of prestressing and access to high performance. be receptive in the current research, with the help of numerical modeling by the proposed method and similar available laboratory results, the effect of the size of the angular dimensions on the expansion of the participation of the beam and column in the shear capacity of the joint area is determined.

In the past, several methods have been proposed to strengthen beam-column connections. Many researchers (Akguzel 2011, Pampanin et al., 2011, Del Vecchio et al., 2015, Cosgun et al., 2019, Hajrasouliha et al., 2019, Ma, Wang et al. 2020) have focused on restoring the lateral strength of the connection area prone to seismic damage. By using polymer materials reinforced with fibers, steel and concrete jackets, the connection area is enclosed. By maintaining the strength of the core concrete, the lost shear capacity of the connection under lateral loads is restored and provides the basis for using the desired bending potential of the beam. Of course, in these methods, by spending the cost, time and total injection of resin and fibers and accepting the risk of sudden failure in the fibers, the achievement of strengthening has been achieved. Also, less attention has been paid to a practical technique for seismic strengthening of beam-column joints; Because the necessity of the methods to destroy the surrounding slab of the connection area and occupying a lot of space is quite evident (Alcocer et al., 1993, Ghobarah et al., 1997, Tsonos 1998, Tsonos 2002, Engindeniz et al., 2005, Karayannis et al., 2008, Tsonos 2010, Santarsiero et al., 2015, Behnam, Kuang et al. 2017, Dang et al., 2017, Nzabonimpa et al., 2017, Torabi et al., 2017, Yang, Chen et al. 2018, Yurdakul et al., 2018, Du, Wei et al. 2019).

Various researchers (Pampanin 2006, Pampanin et al., 2006, Said and Nehdi 2008, Pimanmas et al., 2010, Murad 2020, Deng, Liu et al. 2022, Marchisella et al., 2023), to prevent brittle shear failure of beam-column joints, instead of focusing on restoring the lateral strength of the joint area, focused their strengthening plan on the possibility of reducing the shear stress demand in the joint area. Methods under the title of enlarging the connection area and using hunch arms create a new force path from the beam to the column, and a strong

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strategy is created to ensure the formation of the plastic joint in the beam. Elsewhere Shafai and Nizami (Shafaei et al. 2014, Shafaei et al. 2017, Shafaei and Nezami 2019) proposed a practical seismic strengthening method called "enlarging the connection area using prestressed steel angles". In the proposed method, the beam-to-column connection is done by placing reinforced steel corners in the upper and lower corners of the beam around the beam-to-column connections. Unlike the method of using concrete and steel jackets, it does not lead to architecturally undesirable configurations with bulky members, and since common materials such as angle steel, steel plates and steel bars are used, this method is economical. In this method, the input force demand imposed on the main internal joint is reduced by changing the direction of the force flow around the joint area. The test results showed that the strengthening method significantly delayed the shear failure of the brittle joint and transferred the plastic joint from the column to the outside of the joint region (Shafaei and Nezami 2019). In the current research, based on the control and improved laboratory samples of Shafai et al. (Shafaei et al. 2014, Shafaei et al. 2017, Shafaei and Nezami 2019) according to Figure 1 and Figure 2, wider numerical models are modeled by the proposed method and with the effect of partial and total sliding of longitudinal reinforcements in the connection area. becomes Numerical models include seismic and non-seismic joints without transverse reinforcement in the joint area or without sufficient grip of the longitudinal reinforcement of the beam in the joint area, as well as reinforced joints with angles of 180 mm, 140 mm and 90 mm. After the validation of the models and in the conditions where the limitations of the laboratory conditions and related costs have been abandoned, parametric studies have been carried out. Parameters such as the sliding effects of the longitudinal reinforcement of the beam from the non-seismic and reinforced connection area under monotonic and cyclic loading are investigated. The influence of the amount of seismic weakness of pre-reinforced and reinforced connection on the deterioration of intra-cycle stiffness is judged by observing the difference of the cyclic loading from monotonicity. The effect of angular dimensions in expanding the participation of beam and column in the shear capacity of the joint area is determined. The effect of confinement of transverse beams in reflection with different levels of non-seismic details and also in improved joints is discussed.

2. Methodology

2.1. Experimental study

The specifications of the experimental base beam-column connections are divided into three categories based on seismic details and common non-seismic details in the past construction. The first sample was considered with seismic details, which according to the standards has sufficient silence in the area of connection and capture of the longitudinal reinforcements of the beam (C1). Examples without seismic details (which cover many existing connections) include the lack of column damping in the connection area (C2) and in the last example, in addition to the previous weakness, the beam positive reinforcement did not extend in the connection area (C3). These three samples with similar geometric dimensions are shown in Figure 1 along with the sample assembly.

For connections with previously mentioned seismic weaknesses (C2 and C3), corners with sizes of 180 mm, 140 mm and 90 mm are considered to strengthen them. The details of the numerical models of reinforced joints are shown in Figure 2. Laboratory samples were used from corners with a thickness of 18 mm, steel sheet of 18 mm with a width of 402 mm, and prestressed steel rods with a diameter of 16 mm. The steel plate and the upper and lower corners of the beam remain almost rigid using stiffeners according to Figure 2

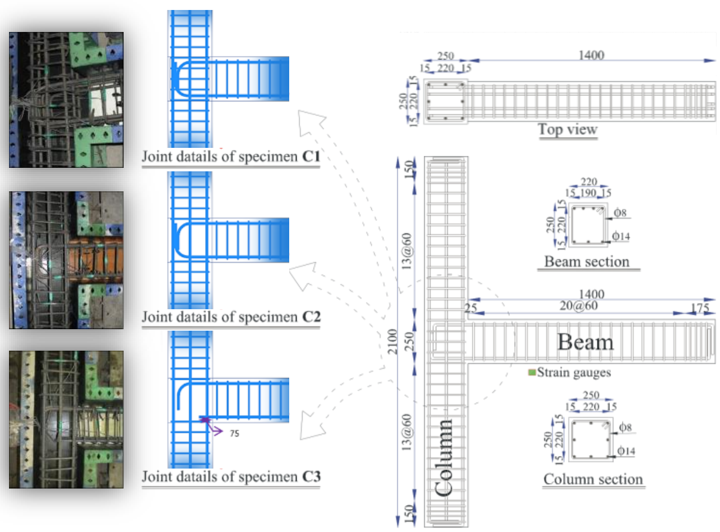

Fig. 1. Dimensions and details of reinforcement of unreinforced test samples (dimensions in millimeters)

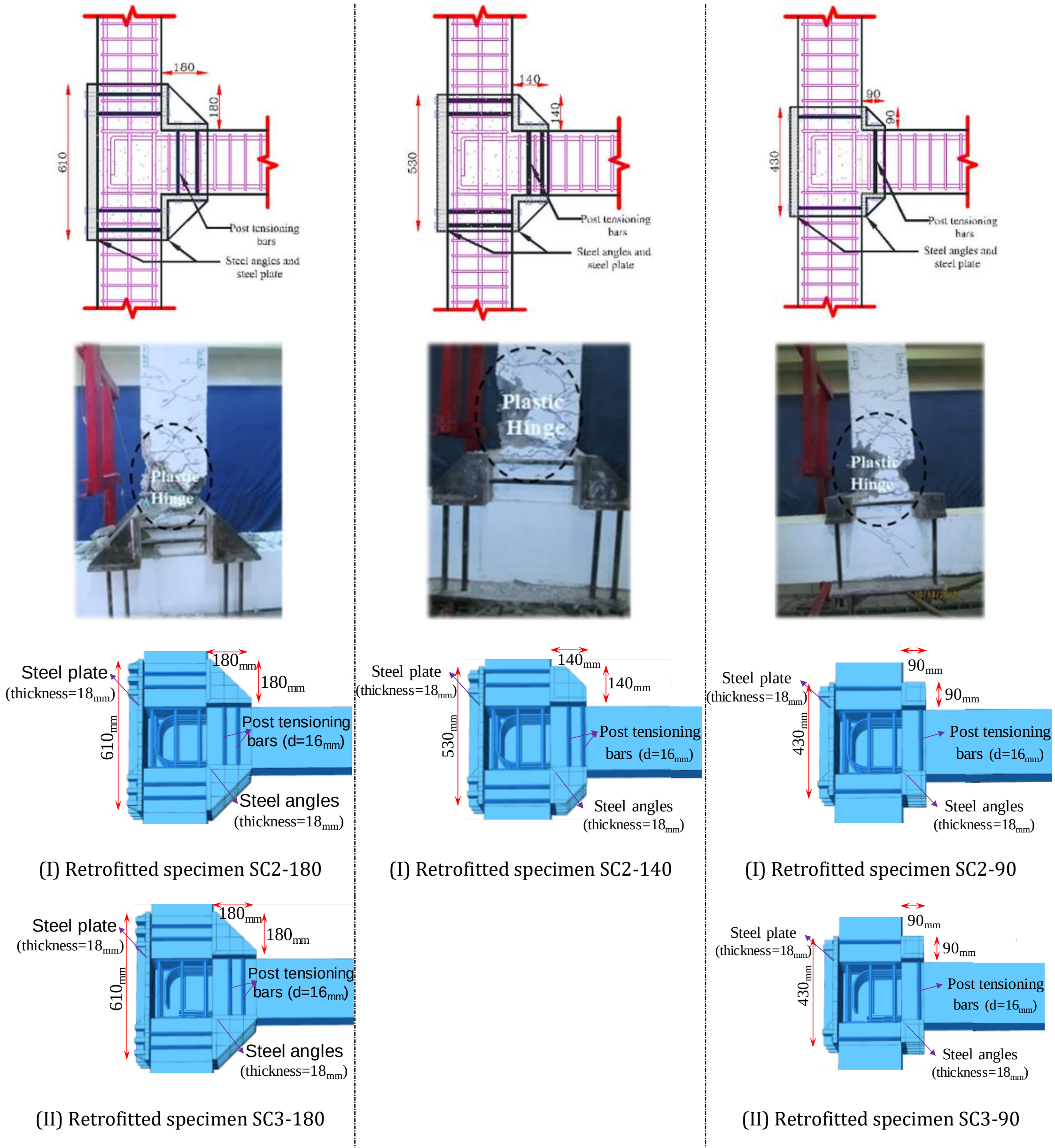

Fig. 2. Dimensions and reinforcement details of reinforced test samples (dimensions in millimeters)

2.2. FE modeling

Micro modeling requires a high level of information. Geometrical conditions, characteristics of used materials, loading and boundary conditions were considered exactly according to the laboratory work. ABAQUS 2018 software was used for modeling and performing all analyses. The concrete damage-plastic model (CDP) was used to simulate the nonlinear stress-strain behavior of concrete in compression and tension. The concrete core of the connection area in C1 samples and the enclosed sections of concrete were modeled by steel parts in the improvement plan in an enclosed form. For the indirect simulation of the sliding effects of bent and unbent reinforcement in the connection area, he used the modification method of the uniaxial strain stress model (Feng, Wu et al. 2018). The details of the models can be seen in Figure 1, Figure 2 and Figure 3.

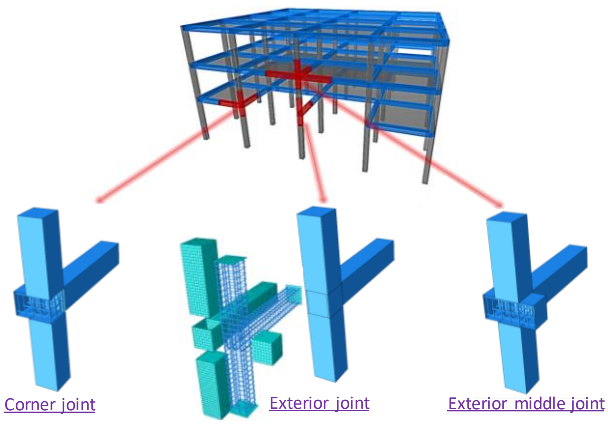

Fig. 3. Different conditions of transverse beams in numerical models

3. Results and discussion

3.1. Reinforcement of joints with different dimensions of enlargement of the joint area

According to Figure 4, the results of finite element analysis for non-seismic connections C2 and C3 show that the use of 180 mm, 140 mm and 90 mm angles to strengthen the non-seismic sample C2 increases the amount of load such as yielding of the connection by 40%, 35% respectively. % and 30%, and the effective hardness increases by 50%, 40% and 30% respectively, and also the ductility increases by 140%, 130% and 120% respectively. Using angles of 180 mm and 90 mm to strengthen the non-seismic sample C3 increases 80% and 40%, respectively, of the yield load of the connection and increases the effective stiffness by 80% and 60%, respectively.

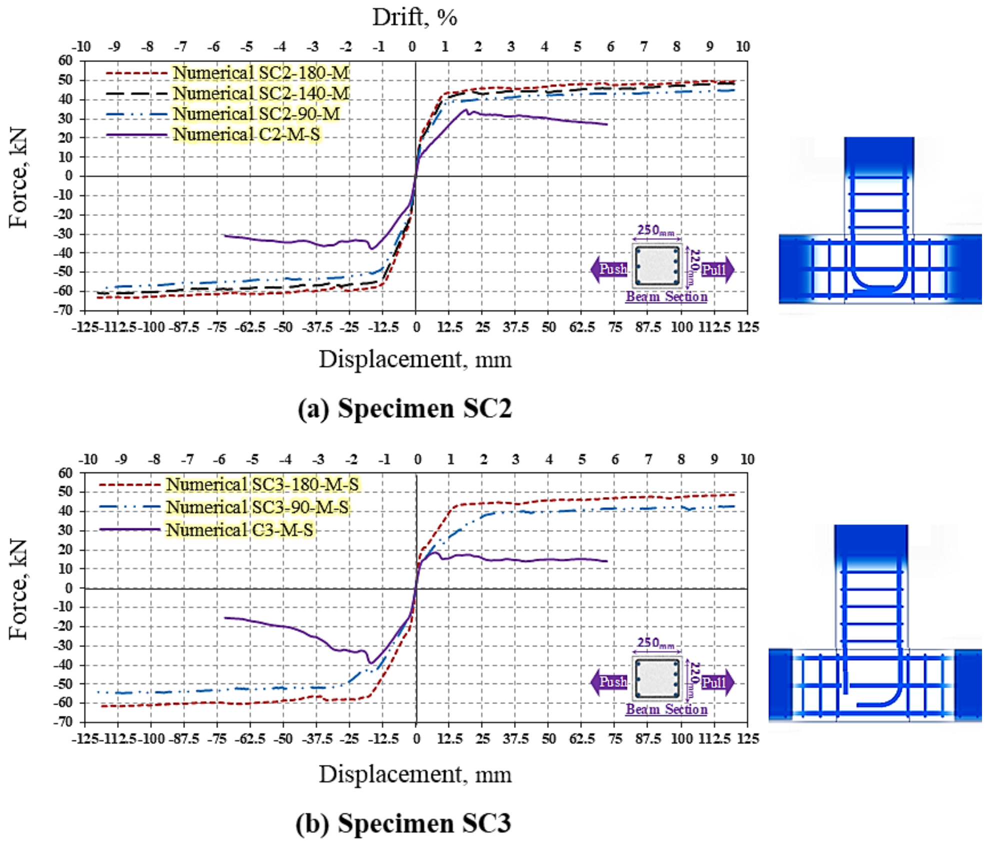

Fig. 4. Displacement load responses of non-seismic connections C2 and C3 along with the results of their reinforcement with different steel angles

3.2. The sliding effect parameter of longitudinal beam reinforcements

In reinforced concrete joints, with the beginning of partial slips of reinforcements and the reduction of friction between concrete and reinforcement, the concrete is gradually crushed and the hardness of the section decreases. With the increase in power demand, the number of cracks increases and the hardness deterioration occurs in a non-linear mode for concrete. At this stage, the micro model shows more bending stiffness than the laboratory model. The improvement percentage of the effective stiffness difference of the models considering the sliding effect of the longitudinal reinforcement of the beam compared to the embedded bound models with the average laboratory results for samples C1, C2 and C3 is equal to 24%, 33% and 80% respectively. Also, the percentage of resistant load difference for models without considering the effect of armature slippage for samples C1, C2 and C3 is equal to 10%, 9% and 8%, respectively. While considering the sliding effect of the longitudinal reinforcement of the beam for C1, C2 and C3 samples, it improves 6%, 5% and 4% load difference such as yielding with the laboratory results, respectively. Adaptation of 40% more stiffness and 5% more load such as yielding by considering the effects of longitudinal reinforcement slips in micro-modeling shows the effectiveness of this method in the appropriate modeling of seismic and non-seismic joints and predicting the effects of partial and total slippage of the reinforcement compared to laboratory results. is.

Taking into account the minor effects of reinforcement slippage in reinforced samples improves (reduces) the effective stiffness by 35% and reduces the load difference by 2.3%, such as yielding of the connection with the test results, and improves the ductility of the connection by 30% compared to models without considering the effect of reinforcement slippage in It is compared with the laboratory results. Therefore, the results show that the more the beam-column connection has seismic weakness, the proposed method in modeling by considering the sliding effects of the longitudinal reinforcements of the beam leads to a greater convergence to the experimental results, and the more the connection by means of reinforcement devices, the greater the force capacity. It should be noted that the difference between the results of both numerical models with and without considering the effect of slip compared to the experimental behavior of the connection results in a smaller difference.

Considering the sliding effect of the longitudinal beam reinforcements in the connection area of the analytical models shows that considering the sliding effect in the proposed method is not only limited to one-way loading, but also for reinforced connections, it makes the response more compatible with the experimental results

3.3. The difference between the results in one-way and cyclic loading

The percentage difference of the average load such as yielding for the cover resulting from the cyclic loading of unreinforced connections and the one-way loading of the same sample compared to the laboratory results is 3% and 4%, respectively. Also, the effective hardness difference percentage for existing connection samples under cyclic loading and under monotonic loading compared to laboratory values is 11% and 16%, respectively. The difference in the results in the type of loading and the greater conformity of cyclic loading with the laboratory results shows that the nature of the type of laboratory loading and the seismic and non-seismic type of the connection has an effect on the degree of conformity of one-way loading to the cover resulting from cyclic loading. Also, in reciprocating loading, unlike one-way loading, intra-cycle deterioration occurs due to the change in load direction. For this reason, the capacity of the model in cyclic loading has been more consistent with the results of laboratory cyclic loading than the similar demands in one-way loading type.

Also, the results show that Posh obtained from the cyclic load-change location curves of the reinforced connection along with the results of the same sample under one-way loading compared to the laboratory results, both have been equally successful in predicting the resistant load of the reinforced connection. This conformity of both types of loading with the laboratory results indicates the absence of intra-cycle deterioration in samples without loss such as reinforced samples

3.3. Effect of transverse beam in reinforced concrete beam-column joints

One of the parameters that is effective in calculating the shear capacity of the connection is the condition of the transverse beam connected to the connection. Whether the connection is enclosed by the beam on two sides or three sides, these are the modes that affect the increase in the power capacity of the connection. The results show the presence of transverse beam on average for non-seismic (C2 and C3), seismic (C1), reinforced with an angle of 9 cm (SC2-90 and SC3-90) and reinforced with an angle of 18 cm (SC2-180). and SC3-180) increases the connection force capacity by 8.5%, 4.7%, 3.6% and 0.7%, respectively. From this exponential increase, it can be found that the more the connection is enclosed by the frame or peripheral devices, the less the effect of the non-conservative presence of transverse beams on the increase in shear capacity. In the case of more confinement of the connection area, the amount of prestressing of stresses perpendicular to the surface of the cracks in the connection area is higher and as a result, the failure of the plastic behavior of the connection area is delayed.

4. Conclusions

Based on the parametric study of the analytical models validated based on the laboratory results conducted elsewhere, it generally showed that in the improvement plan of the side column beam connections in the bending frame of the reinforced concrete structure by enlarging the connection area with the proposed details, enclosing 7% of the length of the beam with reinforcement tools has the ability to increase the maximum bearable force by 30% compared to the non-reinforced sample prone to seismic damage. If the size of the beam is doubled, only 10% more load such as yielding will increase compared to the previous state. If the non-seismic connection is not sufficient for the longitudinal armature of the beam in the connection area, the need to increase the length of the enclosed part of the beam at the level of improving the similar resistance is confirmed. Using angles of 180 mm, 140 mm and 90 mm to strengthen the non-seismic connection without shear reinforcement in the connection area (C2), the effective stiffness increases by 50%, 40% and 30%, respectively, and also the ductility is increased by 140%, 130% and 130%, respectively. It increases by 120%.

Considering the sliding effects of longitudinal beam reinforcements in the proposed method in modeling under narrow sided and cyclic loading can bring 40% of stiffness and 5% of load such as yielding for non-seismic connections to a greater convergence with the experimental response. And this figure for reinforced joints is reduced to 35% for stiffness and 2.3% for load-like yielding. Also, intra-cycle deterioration is confirmed for unreinforced connections and non-deterioration for reinforced connections. On average, the presence of a transverse beam for non-seismic, seismic, and reinforced connections increases the force capacity of the connection by 8.5%, 4.7%, and 2.15%, respectively. From this exponential increase, it can be found that the more the connection is enclosed by the frame or peripheral devices, the less the effect of the non-conservative presence of transverse beams on the increase in shear capacity

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