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Deficient Reinforced Concrete Beam-Column Joint Strengthening

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Abstract – Structural buildings in seismic prone area, the required energy dissipation of strong column-weak beam especially for reinforced concrete frame structures is achievably through adequate beam-column joint strengthening connection in order to have high seismic performance. Literature investigation shows several approaches and techniques for modelling the weak joint for a typical frame structure. This paper extensively reviews those techniques, methods, concepts and their performance in improving the shear capacity for a deficient reinforced concrete beam-column joints in withstanding seismic loads. The beam-column joints performance responses showed positive. However, the need for an improved connection that will offer high ductility capacity and energy dissipation ability for post-tensioned reinforced concrete beam-column joints with continuing bottom reinforcement is highly feasible with the use of the Direct Displacement Based design philosophy. This will be of great interest for the future development of highly efficient joint system for frame structure capable of resisting significant seismic load.

Keywords: RC frame structure; Beam-column connection; post-tensioning; Seismic load

Introduction

The beam-column connection for reinforced concrete moment resistant frame is the weakest structural component when subjected to seismic excitation. The overall ability of the structural unit in proper dissipation of energy and lateral capacity under seismic loading is squarely dependant on joint connection which is based on the design philosophy known as ‘strong-column weak beam concept (Kim and LaFave, 2009). The concept is desirable in achieving elastic behaviour of Reinforced Concrete (RC) beam-column connection. Thorough knowledge of the joint shear characteristics is essential because adverse joint failure will results in affecting the overall performance of the frame in general. There are several publications on the investigations that include both numerical test and analytical studies on the joint performance of RC beam-column connection under earthquake loading. These works are mostly tailored towards the proper understanding of the RC beam-column joint shear behaviour, which is vital in determining the overall building performance of typical frame structures. This paper aims to investigate the trends on understanding the RC beam-column joint shear behaviour characteristic when subjected to lateral seismic excitation. Majority of the seismic prone regions around the globe have invested heavily in mitigating the performance of shear deficient joint of RC beam-column connection testing different joint strength influential parameters. (Kim and LaFave, 2009). However, there are a lots of different and conflicting findings especially on those joint shear strength influencing parameter for RC beam-column (Kim and LaFave, 2009; Uma and Jain, 2006). Although efforts were made to resolved some of the conflicting decisions emanating from researches at several countries (Park and Hopkins, 1989), it is still imperative and informative to bring out to date the overall trends in the joint shear behaviour of RC beam-column connection from all perspective and the way forward.

RC Beam-Column Connection

The geometric configuration aids in classifying the categories of beam-column joints (Park and Hopkins, 1989; Uma and Jain, 2006). This categories could be in-plane, out-of- plane or joint eccentricity (Kim and LaFave, 2009). Figure 1 shows the different in-plane RC beam-column connection subassemblies. An exterior beam-column joint connection has terminating on the column face while the interior consists of dual beam on either column face. The major difference in the joint mechanism is the bar longitudinal anchorages (Uma and Jain, 2006). Hanson and Conner (1967) firstly suggested using free body diagram led to quantitative definition of joint shear of beam-column connection. Since then there are a lots of literature review studies on the design of beam-column connection; for example Uma and PRASAD (2006).

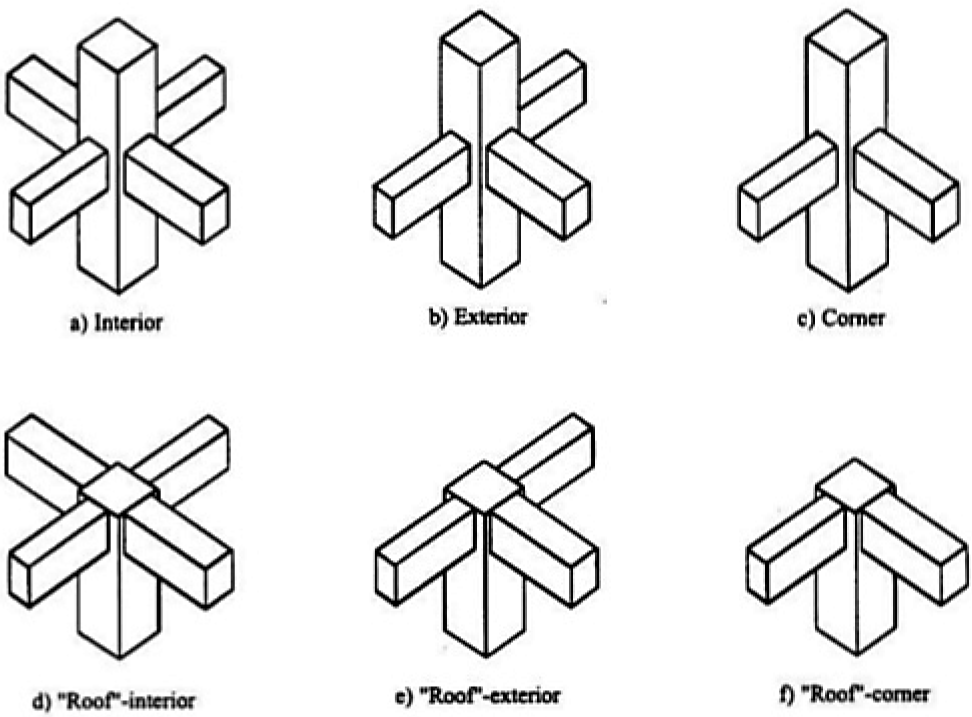

Figure 1 Different joints types configuration for Beam-column connection

Joint Design Approach Criteria

The concrete beam-column connection is very critical section more especially a case of weak beam and column frame under seismic excitations. Many techniques are developed to enhanced the joint capacity of beam-column connection (Alcocer and Jirsa, 1993; Tsonos, 1999). All this have one thing in common to ensure that the joint is stiffer than the adjoining hinging members that include either the beam or column. Different code of practice has unique definition for the joint strength determination. For example, ACI-ASCE (1988) definition for normal joint shear strength is:

$$v_n = \chi_{ACI}\sqrt{f_c^{'} b_j} h_c \tag{1}$$

The parameters χ_{ACI}, $f_c^{'}$ and b_j stands for the joint shear strength factor, the concrete compressive strength value and the effective width for joint shear, respectively. Similarly, h_c represent the column depth. Interestingly, the χ_{ACI} is determined from the vertical forces acting around the joint controlled by the longitudinal and transverse beam ratio.

Japan (1999) has equivalent joint shear strength given as

$$v_j = k\alpha F_j b_j D_j \tag{2}$$

Where k and α are geometry dependant factors for in plane and out-of-plane, respectively. The parameter F_j and b_j are the joint shear strength and its effective width, while D_j stands for the effective column depth.

Zealand (1995) similarly suggested the joint shear strength to be

$$V_z = v_z b_z h_c \tag{3}$$

Where v_z represents the joint shear stress and b_z is the effective width.

Irrespective of the design code of practice, it is paramount to ensure the joint capacity is adequate during the early design stage else the need for modification of either the beam or the column (Uma and Jain, 2006). Design capacity of monolithically jointed frame structure aims to ensure adequate joint ductility especially during earthquake (Li *et al.*, 2008), and this was evident during the earthquakes of 1994 (Northridge) and 1995 (Kobe) where capacity design of certain structures prevented loss of life and properties. However, with growing demands for the provision of structural system with minimal damage exposure during earthquake turns to the use of jointed precast elements.

Furthermore, there are developed numerical model that will aid in determining the behavioural response of hybrid beam-column connection (Hawileh *et al.*, 2010). The performance of the numerical results shows good agreement within the elastic and plastic region. However, it shows the need for further development of numerical hybrid model if comprehensive test results are available (Hawileh *et al.*, 2010). The author added, other issues like geometric conditions, material differences need further studies. That's notwithstanding, there are studies that considers the non-dimensional design for hybrid system where concrete non-linearity, surface contact and pretension are subject of discussion (Hawileh *et al.*, 2006). That study findings reveals a good agreement between the numerical and experimental test result values out at the National Institute of Standards and Technology. However, the high cost and time consuming while trying to study the behavioural pattern of such structure makes the experimental procedure so tasking, hence, the need to search for attractive and simple alternative is timely.

The use of precast elements in structural building offers numerous advantages (Priestley and Tao, 1993). The hybrid system offers a very clean and aids in cost saving more especially the architectural appearance of building (Hawileh *et al.*, 2010). The hybrid consisted of bonded reinforcement bars to the precast element together with unbounded post-tensioned steel bars. Several studies (MacRae and

Priestley, 1994; Priestley *et al.*, 1999; Stone *et al.*, 1995) have demonstrated the performance of the hybrid system over the conventionally designed ductile system.

Use of Precast Elements

Design challenges of precast building in earthquake prone areas is the joint considerations (Yuksel *et al.*, 2015). Different types of ends connection between beam and column such as monolithic, bolted, dry pinned, emulative are available in practice in addition to various proposals and modification. Worthy to mention, the PRESS project is among the notable effort in investigating the seismic response of precast structure (Nakaki *et al.*, 1999; Priestley, 1996). Hawileh *et al.* (2010) proposal of different structural element emanated from the use of precast element tested for seismic performance in San Diego, California. The testing result shows significant performance of the un-bounded post tensioned frame. The significant finding was the ability of the frame element in eliminating residual drift during earthquake. Similarly, the author also recognises that that ability was not capture under the 1997 uniform building code. Although some hybrid connection system are developed in a bid to make the system more reliable and improved the joint ductility considerably during earthquake (Cheok *et al.*, 1994).

Many techniques are developed to enhanced the joint capacity of beam-column connection (Alcocer and Jirsa, 1993; Tsonos, 1999), such example include the use of steel corrugated plate. The method employs the use of steel-to-steel armouring at the joint faces of the beam column connection, and found to be effective in avoiding large seismic displacement damage under earthquake (Arnold, 2004; Davies, 2004), but it is expensive (Li *et al.*, 2008). However, literature evidence shows the needs for adhesive at the joint, because it will aids corrosive protection (Mukherjee and Joshi, 2005). This focuses the attention to the use of FRPC because of its ability in making the joint more ductile. However, the complexity and lack of clear information on beam-column connection makes the use of such method under seismic condition more difficult (Mukherjee and Joshi, 2005). There are several experimental studies on evaluation the performance of RC beam-column joint enhanced with laminates.

Experimental Evaluation of RC Beam-Column Joint

The seismic performance of beam-column connection of typical RC structure is its measure of the joint shear appraisal. The push-pull (cyclic) method of testing the shear strength of FRP strengthened joints is sometimes quite difficult to accurately measure and monitor its real behaviour (Shrestha *et al.*, 2009). Several studies were conducted to test the shear efficiency of FRP strengthened joints of beam-column subjected to both cyclic and monotonic loading cases, for example the study by Shrestha *et al.* (2009). Prizzi and Raimondo (2013) attempts to study two different methods (precast and cast in place) upon previously tested (fails under cyclic loading) specimens by repairing using SHCC as strengthening material. The author findings reveal a significant performance by both methods.

Yen and Chien (2010) study on the suitability of plate bonding techniques on enhancing monotonic load capacity at the joint of RC beam-column connection. The study finding shows good enhancement for both ductility and flexural capacity, and this was demonstrated in a similar study conducted by Popov and Bertero (1975). The former author strengthened the joint of beam-column connection using steel plate and glue attached to the concrete beam in three different directions. The author result also reveals the gained of significant strength and stiffness improvement under cyclic loading condition. Similarly, all tested specimen shows high strength and satisfactory ductility. On contrary, the use of steel plate alone without the epozy will result in brittle failure. However, despite those advantages, the author could not developed reasonable conclusion from those studies.

To salvage the difficulties in detailing of beam-column bars at the joint, a technique known as upgradation was proposed by Mukherjee and Joshi (2005). This leads to the investigation of the beam-column behaviour under cyclic loading casted with under enough and less reinforcement conditions, and the application of FRP plate's strips sheets at the joint. Some study finding using this method reveal high joint strength irrespective of the amount of the reinforcement or its proper details, and this resulted in significant increase in joint yield load before failure. However, the process is acknowledge to be a difficult one (Mukherjee and Joshi, 2005).

Attari *et al.* (2010) examines the influence of external strengthening of RC beam-column joints using CFRP laminates and GFRP sheets against cyclic loading. The author experimental study consist of three element tested under pre-stressing axial column load where end to end cyclic loading of the beam under displaced control mimicking seismic action. The study findings revealed the effectiveness of the CFRP laminates in retrofitting RC beam-column connections. Similarly, the combined use of CFRP and GFRP laminates will significantly improve the joint shear capacity and ductility requirement of deficient RC beam-column connection. Several other related studies are conducted in that area (Gergely *et al.*, 2000; Ghobarah and El-Amoury, 2005; Mukherjee and Joshi, 2005). However, literature findings still show that systematic studies on retrofitting of deficient joint of RC beam-column connection under cyclic excitations are limited (Al-Salloum *et al.*, 2010; Attari *et al.*, 2010; Ronagh and Eslami, 2013).

Recently, Ronagh and Eslami (2013) carried out study to examine the effectiveness of FRP in retrofitting deficient joint of RC beam-column connection. The finding revealed that implementing non-linear push over analysis lumped plasticity, the joint shows a significant increase in load carrying capacity. Literature findings similarly corroborate that result (Attari *et al.*, 2010; Dalalbashi *et al.*, 2012; Le-Trung *et al.*, 2010; Mahini and Ronagh, 2011). More so, known problems such as FRP-concrete interphase and creep behaviour were investigated in many studies (Ascione *et al.*, 2008; Ascione *et al.*, 2005; Yuan *et al.*, 2012). Balsamo *et al.* (2005), studied the seismic behaviour of deficient RC beam-column joints repaired with CFRP laminates and wraps. Interestingly, the author's findings revealed large displacement capacity at the joints with the application of FRP laminates. Similar other studies were conducted by Di Ludovico *et al.* (2008), which also shows similar performance of the retrofitted joint, and this is also confirmed by (Garcia *et al.*, 2010).

Al-Salloum *et al.* (2010) tested the efficiency of RC beam-column joints reinforced with CFRP by comparing the experimental performance to an ACI joint-based design specimen. The study results compares well with the ACI code provision. The research contributions over the decades about seismic excitations effect on joint deficient of RC beam-column connection using different external laminates are many. For example, Hanson and Conner (1967), Hwang and Lee (1999), Hwang and Lee (2000), Baglin and Scott (2000), and Karayannis and Sirkelis (2008).

Antonopoulos and Triantafillou (2003) study on the behaviour of exterior RC beam-column joint strengthened with FRP aims to understanding the joint shear behaviour. The author uses 18 specimens, and places emphasis on the hysteresis loop behaviour, the joint stiffness and its energy dissipation capacity. The study result indicates about 70 – 80% gained in cumulative energy dissipation at the joint in addition to the observed increase in joint stiffness. However, the author hinted the need for further study that will focus on understanding the joint response if considering rebar pull out mode from the joint failure condition. Similarly, Gergely *et al.* (2000) study findings on series of 1/3 scale

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exterior beam-column strengthened with carbon plates show that FRP provides a good solution in improving the joint shear capacity.

Lee *et al.* (2010) proposal for an effective rehabilitation strategy that aims to enhance the strength and stiffness of the RC beam-column joint is found to be effective. More so, Pantelides *et al.* (2008) application of external CFRP jackets for the seismic retrofitting of deficient RC interior beam-column joints that are designed for gravity loads. It's all on the avoidance of damage to the structure, and is investigated in many studies (Cheng and Mander, 1997; Davies, 2003; Mander and Cheng, 1997). The method could significantly mitigate any potential risk to the RC beam-column joints under large seismic displacement. The development of advanced computer codes simplifies the mimicking of the experimental performance of RC beam-column connection.

Numerical Investigation of RC Beam-Column Joint

Several analytical studies are developed to appraise the performance of the beam-column joint strength, notwithstanding the difficulties that lies with the behaviour of the strengthened beam-column connection. Antonopoulos and Triantafillou (2002) study the analysis of joint behaviour strengthened with FRP comprising unidirectional flexible fabrics where the study model provides strain and stress equation for the joint behaviour at different yielding points. The use of FRP numerical joint analysis studies is rather limited still (Antonopoulos and Triantafillou, 2002). Gergely *et al.* (1998) study results shows a significant contribution to the shear capacity of beam-column joint using FRP with the assumption of crossing potential shear cracks in beams exhausting its tensile capacity zone. Similar assumption to previous discussion were adopted by Tsonos and Stylianidis (1999), and the assumption baseline argument checked by Gergely *et al.* (2000) where the concrete strain values are fixed between 0.0021 – 0.0035. However, researchers are of the view that those assumption are rather too simplified which may not capture the real stress-strain behaviour (Antonopoulos and Triantafillou, 2002)., and this is primarily due to the fact that there is a possible premature deboning of FRP at the joint below the fracture strain.

In the year 2012, a binomial regression model is developed for estimating the qualitative in-elastic joints mechanism probabilistically, subjected to geometric and materials parametric evaluations (Mitra, 2012). The model could aid in assessing the joint ductility response of beam-column connection because it shows a satisfactory performance based on *p-value* statistical analysis. However, there a suggestion for further experimental study in validating those parametric parameters considered in its study. Similarly, Tran *et al.* (2014) presented a new empirical model capable of estimating joint shear strength of beam-column connection for both interior or exterior connections. The model considers the four joint shear strength-influencing parameters of beam-column connection in addition to the bond condition including the possibility of shear transfer from beam to column. The author validates the model performance through testing upon several literature databases that comprises both interior and exterior beam-column connections.

Several factors influence the performance of the joint shear capacity of RC beam-column connection. For example the joint reinforcement ratio, etc.. Literature have shown cases where the beam-column joints are constructed without transverse reinforcement, and this is sometimes known as under-reinforced joints (Park and Mosalam, 2012), and are widely used in seismic prone region globally. In the early 1970s, such design consideration of under-reinforced joints are not captured in the design codes while their effect on the joint shear performance is massive specifically on seismic prone regions (Park and Mosalam, 2012). There are a lots of literature on the performance of under-reinforced joints behaviour of beam-column, and different shear performance proposals are made

(Bakir and Boduroğlu, 2002; Vollum and Newman, 1999), and are mostly on empirical models. Although some advanced models are also found in literature (Park and Mosalam, 2012), but accurate prediction of shear behaviour of under-reinforced beam-column still posed a challenge.

Niroomandi *et al.* (2014) present a parametric evaluation of RC beam-column without transverse reinforcement and its result corroborates literature findings that show the influence of joints aspect ratio and beam longitudinal reinforcement ration as its governs the shear behaviour beam-column joints. Similarly, the author findings also reveal that the correct selection of these joints shear strength-influencing parameters is extremely important in the design of RC buildings because wrong selection will result in a dire consequence.

Sharma *et al.* (2011) presented a model to predict shear behaviour of poorly detailed beam-column joint by limiting the principal tensile stress as the failure criterion, and its performance is quite impressive. The author model uses spring with non-linear principal tensile stress-strain under both static and dynamic condition. In a related development, Shin and LaFave (2004), similarly presented a rational method for the determination of non-linear hysteretic joint performance of beam-column connection. The author employed the use of modified compression field theory in developing joint shear stress-strain responses, and the model shows good representation of the joint shear hysteretic behaviour.

Park and Mosalam (2012) evaluated the shear performance of under-reinforced exterior beam-column joints where experimental data's are sought from vast literature findings. The study results show that joints behaviour are mainly influenced by the joint aspect ratio and the joint shear index respectively. Hence, with the used of those influencing factors on joint shear behaviour of beam-column leads to the development of a model for the joint shear performance. The model results indicate that the joint strength reduces with increasing joints aspect ratio. Similarly, the joints aspect ratio suitably defines the upper and lower bounds of the joints shear capacity, and the shear strength is proportional to the joint shear index. Similarly, Hegger *et al.* (2003) empirical model that considers both joints and column aspect ratio and the results shows the conservativeness of the joints shear strength. That author reaches the conclusion that the consideration of column steel ratio may not have contributed to the overestimation of the joint shear strength, thus it is not an influencing factor in appraising the shear behaviour of RC beam-column connection. Furthermore, Hwang and Lee (1999) similarly developed an analytical model for predicting joints shear capacity using SAT idealization. The author developed iterative procedure for the numerical solution to the beam-column shear capacity is best suited in predicting shear strength capacity. However, critics have outlines the inappropriateness of the model capacity due to some reason; for example, the strain equation used are not compatible for under reinforced joints and the method only beneficial when considering column axial load only (Park and Mosalam, 2012).

More so, literature evidence have shown that even the advanced developed model for the determination of shear strength capacity of beam-column joints gives conflicting results and lacks clear accuracy (Song *et al.*, 2010). That development had led to the undertaking of many fundamental researches in addressing that drawback. For example, Song *et al.* (2010) developed a probabilistic model for the determination of beam-column shear strength using Bayesian parameter estimator. The author study results from the use of its developed model showed an improved estimation of the joint shear strength with more accuracy.

The principal interest in this paper lays with the shear strength-influencing factors for the beam-column connection under seismic loading. The preceding section presents some relevant literatures on that regard.

Shear Strength Influencing Factor under Seismic Load

The development of generally acceptable shear strength model of RC beam-column connection especially under seismic activities still posed a challenge among the research community due to the most probable reason of the joints complex behaviour (Wang *et al.*, 2012). As mentioned previously, there are several factors that influences the joint behaviour such as reinforcement ratios, joint geometric, axial column load location etc., and literature evidence shows extensive investigation on the effect of these parameters on the joint performance as previously noted (Otani *et al.*, 1984).

Wang *et al.* (2012) presented study findings on the determination of RC beam-column joints shear performance from a new shear strength model. Significantly, the new developed model takes into account both the intermediate and the transverse steel ratio by idealizing nominal tensile strength of the joints materials. The author study findings reveal the model accuracy by comparing results of 106 literature test results that comprises both interior and exterior beam-column joints. Similarly, some literature evidence are also available that shows the probabilistic evaluation of beam-column joints shear strength (Kim *et al.*, 2009).

In the year 2006, a method capable of predicting the ductility behaviour of beam-column joints with the formation of plastic hinges at the joints is presented (Jung-Yoon *et al.*, 2006). The model takes in to accounts the joints shear deformation. The suitability of its proposed method was validated through testing the behaviour of 48 joints failure conditions, and the result showed a reasonable agreement. Most studies on the performance of RC beam-column connection employed the use of Modified Compression Filed Theory (MCFT) or the strut and tie method (A653). However, the limitation of these methods is that it is difficult in effectively applying to determine the shear capacity of RC beam-column behaviour (Long and Lee, 2015). Although the STM may predict the ultimate shear strength, Long and Lee (2015) developed an improvement upon the STM method which is capable of predicting critical shears at all stages of the strain-stress relationships for RC beam-column joints. The authors improved method was found to compares well the experimental study results but little information is known regarding those shear strength influencing parameter on the joint shear behaviour of RC beam-column connection.

The challenges faced in correct characterization of RC beam-column joint shear capacity as previously shown attract interest from both numerical based solution and experimental studies. Daniels *et al.* (2015) conducted a series of numerical finite element analysis of RC beam-column joints reinforced with and without FRP. Its findings reveal for a column confinement in addition to flexural reinforcement, the model joints capacity increases by 10%, and this prevents the columns bars from yielding thus reducing the likely damage to the joints of RC beam-column retrofitted with FRP. The increased in the joint capacity is a positive development because this will prevent premature structural collapse. However, the limitations in terms of recognizing all deterioration cases and their interaction within the model may hampers the result as literature shows (Lopez-Almansa *et al.*, 2014). Interestingly, Super Elastic Shape Memory Alloys (SESMA) are now in use in order to improve the joint capacity of RC beam-column connection. The SESMA has the tendency to undergo large deformation under stress and returning to its original shape after stress removal. For example, Youssef *et al.* (2008) conducted test on determining the joint behaviour of RC beam-column connection reinforced with SE SMA, and found that SMA retrofitted joints shows significant recovery from post-yield deformation. Since then the use of SMA usage have gained significant interest in retrofitting application (Alam *et al.*, 2007; Clark *et al.*, 1995; Dolce *et al.*, 2004; Tamai *et al.*, 2003).

Post-tensioning Tendons for RC Beam-Column Joints

The quest for improving the joint shear capacity of RC beam-column connection especially subjected to seismic loading continues to strive more in order to attenuate the risk associated when such joints fails. The use of post-tensioning tendons strengthening of RC beam-column joints increases the joints shear resistance significantly. Literature shows many innovative and efficient post-tensioning techniques were successfully applied to the RC beam-column connection where the ductility is significantly increased (Iqbal *et al.*, 2010; Priestley, 1991, 1996; Priestley *et al.*, 1999). Under this method, the prefabricated ductile joint connection of the deficient RC beam-column increases the inelastic seismic demand especially during earthquake by accommodating the demand within the joint through mitigating the gap while maintaining the elastic safe range of the structure (Stanton *et al.*, 1997). Interestingly, the use of post-tensioning in retrofitting the joint of RC beam-column connection will result in negligible residual deformation which is because of the tendon re-entering capability (Iqbal *et al.*, 2010).

Experimental study on RC beam-column joint strengthening with the use of unbounded post-tensioning is presented by the author Gião *et al.* (2012). The author includes the jacketing of the RC beam with Unidirectional Fibre Reinforced Group (UFRG). The inclusion of UFRG is to limits compression damage during confinement by delaying the concrete crushing and yielding of the reinforcement bars. The study revealed that the RC beam-column joints retrofitted with external post-tensioning will results in increasing the joints capacity of RC beam-column. No doubt that the improvement of seismic structural behaviour of framed structured system requires the enhancement of hysteretic behaviour of the joint component (Gião *et al.*, 2012). By improving the beam-column connection it will significantly enhanced the energy dissipation of the joints (CEB, 1994). Under seismic excitation, most literature shows the improvements can attain through the modification of the vertical members including the joints itself (FIB, 2003). Several research findings shows the damages to the vertical elements during earthquake failure because it is technically more difficult in attaining proper strengthening due to the monotonic connection with the slab (Gião *et al.*, 2012). This behaviour could be attributed due to the lack of continuity of bottom reinforcement over the support, and this will leads to increase in lateral deformations (Bracci *et al.*, 1995; Calvi *et al.*, 2002; El-Attar *et al.*, 1997). Hence, it will interest to find out the joint shear behaviour post tensioned together with the continuing bottom reinforcement.

Notwithstanding the above limitation, because of the promising seismic resistance behaviour of post-tensioned precast beam-column joint subassemblies different other studies like time history analyses that led to several proposals. This was in response to the recognised need for more research and explorations on precast system for seismic regions. For example, El-Sheikh *et al.* (1999) carried out experimental study on the seismic behaviour response of unbounded post-tensioned precast concrete joints for frames. The authors developed two analytical models for the analyses comprising the fibre and the spring models. The study findings show a promising performance in strength and ductility enhancement of the joint. Decades ago, similar study was undertaken in order to developed guidelines for economical RC beam-column connection by Cheok and Lew (1993). The work considers the location of post-tensioning strands; fully and partially bonded conditions. The authors findings revealed that post-tensioned precast specimens had comparable higher connection strength and ductility with lower energy dissipation. This desirable seismic performance for post-tensioned energy dissipations capability is independently verified (Christopoulos *et al.*, 2002). In that verification study, the findings similarly showed that test specimens were able to undergo large inelastic displacement without any damage to the beam or the column without residual drift (Ricles *et al.*, 2001).

Furthermore, several other studies conducted to explore the response of frame with partially un-bonded tendons by means of dynamic inelastic hysteresis analysis. The literature shows that the hysteresis characteristics represent the true joint behaviour. However, despite the positive results, the force-displacement response is less than 35% larger than elasto-plastic system for medium to long term displacement (Priestley and MacRae, 1996). This behaviour was because of the development of plastic hinges that exhibits less efficient loops than elasto-plastic system. Structures fitted with un-bonded tendons at the joints of RC beam-column connections are to show resilience to seismic shock with low displacement. Among other advantages on the use of un-bonded post-tensioned precast frames, include the ability of shear resistance capacity of the beam. This will reduce the transverse reinforcement requirement considerably. Similarly, there would be significant reduction in horizontal joint shear reinforcement requirement because of the shear transfer mechanism by diagonal compression strut action (Priestley and MacRae, 1996).

Summarily, the major deficiency of RC beam-column connection as highlighted in most of the literature-investigated points to inadequate seismic design, lack of continuity of bottom reinforcement over support in addition to limited deformation capacity. Significantly enough, the lack of bottom reinforcement bars at support leads to an increases in lateral deformation (Bracci *et al.*, 1995; Calvi *et al.*, 2002; El-Attar *et al.*, 1997; Gião *et al.*, 2012). The mitigation of this problem sounds positive with the use of curvilinear post-tensioned tendons at the support together with an external wrapped. However, the viability of such ambitious method can only be proven if found worthy through both experimental and numerical tests. The authors' future challenge is to investigate the seismic performance of the joints strengthened with curve linear post-tensioned tendons wrapped with metal.

Conclusion

The development of new seismic resisting system for RC beam-column connection with enhanced joint ductility with more energy dissipation capacity using post-tensioning technology, originally made for precast concrete in combination with external wrapped is not only timely but essential with growing threats to life and properties for RC frame structure especially in seismic prone region. This paper extensively reviewed the known techniques, materials, concepts and important factors influencing the joint shear capacity of RC beam-column connections of framed structure responses to seismic load. Literature shows several promising findings in enhancing joints of the RC beam-column connection where an analytically predicted response compares well with experimental subassemblies. Notwithstanding, the quest for an improved connection for RC beam-column with high ductility capacity and energy dissipation ability will look inwards to the experimental and numerical investigations for the viability for the post tensioned RC beam-column connection with continuing bottom reinforcement especially employing the Direct Displacement Based design philosophy. This will be of great interest for the future development of highly efficient joint system for frame structure capable of resisting significant seismic load.

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