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Numerical simulations of the bond stress-slip effect of reinforced concrete on the push over behavior of interior beam-column joint

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Abstract. Structure failure often occurs in the joint. This failure can adversely affect the comfort level of the structure. Knowing the behavior of interior beam-column joint structure resulting from the load is important, as it can help to predict the strength of the structure interior beam-column joint and comfort of the structure being worked on. One way to find out and predict the strength and comfort of the structure interior beam-column joint as a result of the load received is the experimental test and simulation. The simulation VecTor2 used to predict the shear force, crack, and displacement of the reinforced concrete column when applied the shear force. This simulation considered the effect of the bond stress-slip effect of behavior reinforced concrete. Bonds stress-slip gives a great influence on the strength and hysteretic response of the reinforced concrete beam-column joint. That is why this study considers the influence of the bond stress-slip on a reinforced concrete column. All the result of simulation VecTor2 using bond stress-slip effect would be compared with the result of the experimental test to see the behavior and accuracy of the simulation test.

1. Introduction

A few years ago, many of building collapse because of the earthquake and made so many victims. Studied from this case engineer must have the capability to design a good building and safety. Most of the reinforced concrete failures occur not because inadequacies in the analysis of the structure but the failure can be occurred because of inadequacies attention to the detailing of reinforcement building like joints. Even though some engineer take care to design like walls, footings, beam, and column but for ductile behavior beam-column joints they forget to consider and sometimes they ignore it. Basic assumptions of the frame analysis that the joints are strong enough to sustain the forces (moments, axial and shear forces) generated by the loading, and to transfer the forces from one structural member to another. Performance of structure not only depends for individual structural elements but also upon the integrity of the joints.

Recently many research has been directed toward establishing a better basis for the beam-column joint design. The recommendation provided a basis strong for the safe design of beam-column joints, so with this recommendation will not find again design for joint, vertical column bars, horizontal beam bars, and material overlooked. Post-earthquake analyses of structures, accidental loading or laboratory tests show that the distress in the joint region is the most frequent cause of failure, rather than the failure of the connected elements (Saatcioglu et al. (2001) and Rai and Seth (2002), Park and Paulay (1975). Analytical models which simulate the response of reinforced concrete interior beam-column joints have been developed

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(Mitra and Lowes, 2007).

Many experimental and analytical investigations various of beam-column joints model over the past two decades. As for analytical and experimental done to know the behavior and failure of the beam-column relationship (interior joint, exterior joint, and corner joint). Shiohara and Kusuhara (2008) doing experiment test for 10 specimens with different loading and parameter. This experiment test gave us some information for behavior beam-column joint. Another case for this analysis also using experiment data from National Center Research Earthquake Engineering (NCREE) for specimen exterior beam-column joint.

2. Literature Review

2.1 Interior Beam-column Joints

Joints is of great importance for design building that is why joint design has been always seriously particularly when design because when joint fail it can make some building collapse and crushed. Actually joints should have adequate strength and stiffness to resist the internal forces induced by the framing members. Figure 1 shown satisfy equilibrium in the joint behavior of the shear force and the diagonal concrete compression field of the reinforcement in the orthogonal directions.

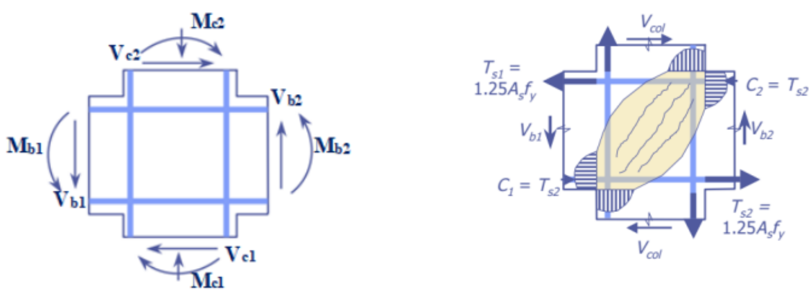

Figure 1. (a) Moments, shear, axial loads acting on joint. (b) Internal stress resultants acting on joint (Eom, T.S., Hwang, H.J., Park, H.G, 2015).

Many factor influence cracking, yielding, and failure of concrete and usually random process. This behavior we can found and presented by test observation and we can also predict by simulation test. Control the crack that occurs in the beam or column is usually used a larger number with a small diameter bars, that is why the distribution of reinforcing concrete is very important in the tensile zone and stress zone to reduce the failure. Shear deformation for the joint produced cracking, bond slip, and bar pull out across a member we can saw at Fiure 2.

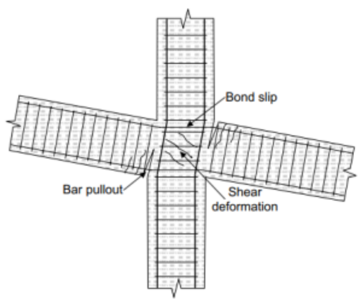

Figure 2. Deformed reinforced concrete (Altoontash, 2004)

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2.2 Modeling Vector2 (VT2)

The main focus of this study was to understand the modeling capabilities of VecTor2 under monotonic loading and also displacement loading control conditions for structure. Therefore, a variety of the types of connections, material properties and connection details examined was crucial for confirming the applicability of the program or identifying it is limitations. The specimens consisted of reinforced concrete wall and seismically and non-seismically designed wall that was analyzed under simulated seismic loading conditions similar to those followed during the experimental tests. The modeling efforts were utilized using the default behavior or constitutive model options in order to prove that the program successfully captures the necessary response parameters without any modifications to the structure details.

The study of the bond material behavior at the interface between reinforcement and concrete was one of the focus of this research. This research formulated "how to calculate the shear force, displacement, and crack prediction that occurs for interior beam-column joint, exterior beam-column joint, beam, column, and wall when applied the axial force and displacement loading control. To know the behavior of structure it's important to predict some failure which one occurred for structure or element.

3. Calculation of Bond Stress-Slip Models of Interior Beam-column Joint

Simulation VecTor2 consider the effect of bond stress-slip models for embedded bars. effect this model giving an impact on the behavior of reinforcement and concrete. This condition considers the behavior of friction between concrete and steel reinforcement of beam load. This behavior determined by confinement pressure factor (β), which one of this condition determined by linear interpolating between the unconfined and confined reference bond stress and slip. This simulation doing try and error to predict the value of bond-slip confinement pressure, which one this value arrange between $0 \le \beta \le 1$. The value of bond stress-slip of beam-column joint would calculation with:

$$\beta = \frac{\sigma}{7.5} \quad \ldots 1$$

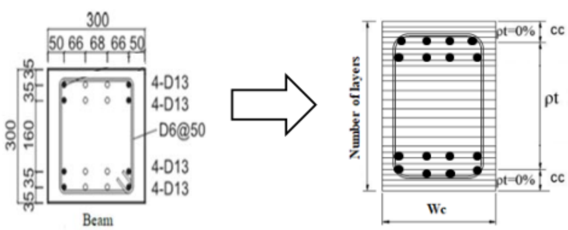

Figure 3. Detail of transverse reinforcement ratio of interior beam-column joint

$$\rho t = \frac{2xAb}{stxwc} = \frac{2x32.2}{50x300} = 4.286x10^{-3} = 0.4286\%$$

$$\beta = \frac{\sigma}{7.5}; \text{ (in MPa) } 0 \le \beta \le 1$$

$$\sigma = \rho_t \text{ x } f_y = 0.004286 \text{ x } 326 = 1.3972 \text{ MPa}$$

$$\beta = \frac{\sigma}{7.5} = \frac{1.3972}{7.5} = 0.186$$

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4. Simulation and Experimental Test

4.1 Analysis Interior Beam-Column Joint by Simulation VecTor2

Material properties for the concrete and reinforcement test are listed in Table 1 and Table 2. At the top of the column for the experiment test was applied an axial load 216 kN and loading displacement control by the reversed cyclic load.

Table 1. Reinforcement properties interior beam-column joint

Test Series	Reinforcement Properties		db (mm)	Ab (mm²)	Es (MPa)	Esh (MP)	fy (MPa)	fu (MPa)	ε_u x10⁻³
D1	Beams	D-13	12.7	126.61	176000	952	456	582	160
	Columns	D-13	12.7	126.61	176000	1032	357	493	160
	Hoops	D-6	6.4	32.15	151000	5391	326	488	15.7

Table 2. Concrete properties interior beam-column joint

Test Series	Ec (Mpa)	f'c (MPa)	ε'_c (x10⁻³)	f't (MPa)
D1	30000	30.4	2.03	2.9

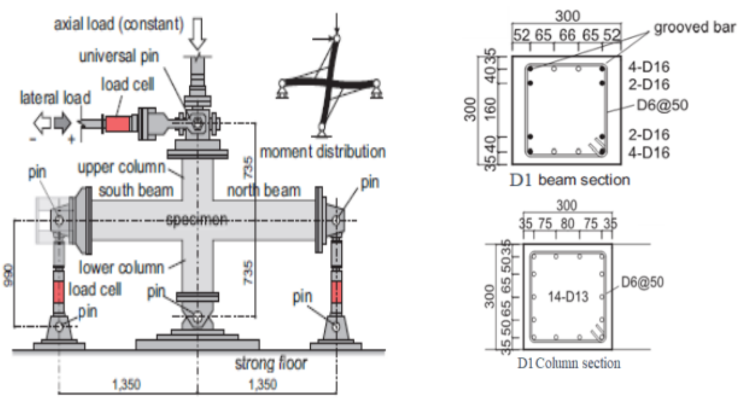

Figure 4. Test set-up specimen D1 (Shiohara and Kusuhara, 2008)

For analysis interior beam-column joint by the Vector2 code must provide and build up the region of the specimen test. Table 3 show the region and parameter of specimen interior beam-column joint and figure 5 shows the test set up and modeling of interior beam-column joint D1.

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Table 3. Region type and parameter design VecTor2

Region Type	Member Type	Mesh size (mm)	Vertices x	Vertices y	Region Type	Member Type	Mesh size (mm)	Vertices x	Vertices y
Region1	Beam	25x25	0	585	Region4	Beam	25x25	1200	0
			0	885				1200	0
			1200	885				1500	585
			1200	585				1500	885
Region2	Beam	25x25	1500	885	Region 5	Beam	25x25	1200	885
			1500	585				1200	1470
			2700	585				1500	1470
			2700	885				1500	885
Region3	Beam	25x25	1200	885					
			1200	585					
			1500	585					
			1500	885					

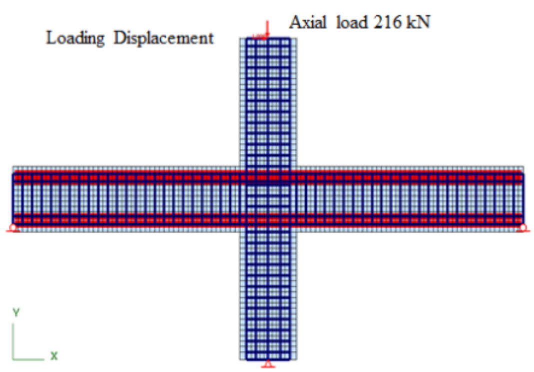

Figure 5. Test set-up simulation VecTor2 specimen interior beam-column joint for axial load and displacement load

Figure 6 shows the crack, stress tension, and strain tension of the experiment test and simulation by the VecTor2 code at story drift 4% and bond-slip confinement pressure 0.186.

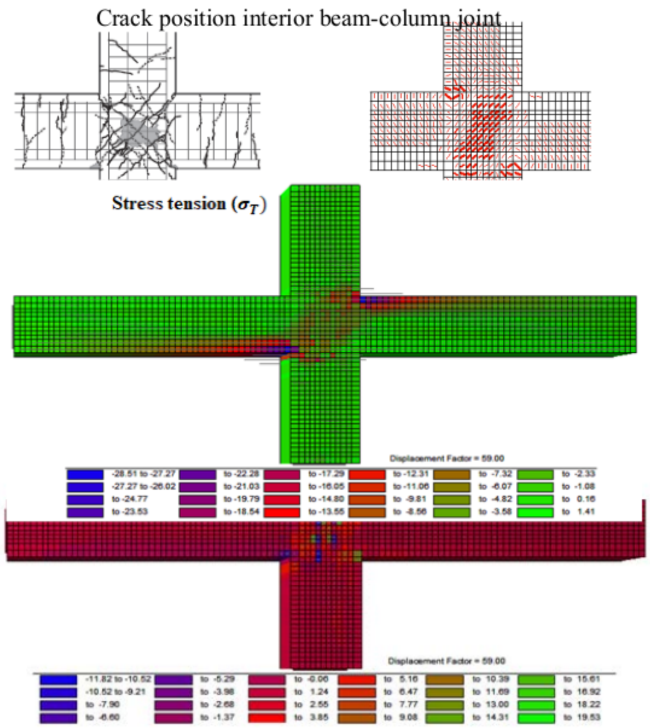

Figure 6. Comparison crack, stress tension, and strain tension of specimen D1 at story drift 4%.

Table 4. Comparison results experiment test and simulation VecTor2 interior beam-column joint D1

Specimen (D1)	**Experimental Test**	**Simulation VecTor2**	**Ratio** $= \frac{VT2}{Exprt}$
Peak Load, (kN)	133.9	131.2	0.98
Load at first Beam Yielding, (kN)	89.7	131.2	1.46
Beam Yielding Displacement , (mm)	12	21.68	-
Bond slip calculation	-	0.186	-
Bond slip try and error	-	0.02	-
Behavioral Failure Mechanism	Beam Yielding, Joint Failure (BYJF)	Beam Yielding, Joint Failure (BYJF)	-

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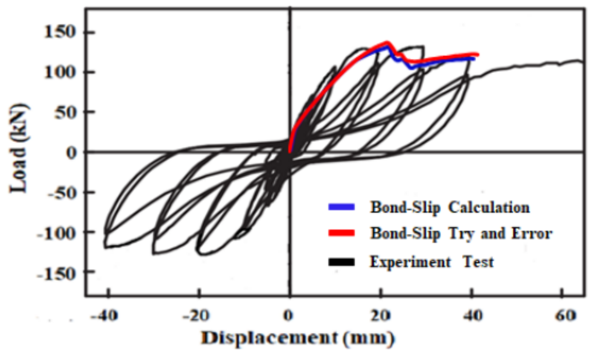

Figure 7. Hysteretic loop combination experiment and VecTor2 analysis for specimen D1

5. Conclusion

Simulation Vector2 for interior beam-column joint, give some conclusion to predict the behavior of reinforced concrete and the condition would be compare with the experiment test. Some of the conclusions that we can get from the results of this simulation are:

1. Simulation VecTor2 use the bond stress-slip embedded bars can predict the behavior of interior beam-column joint to see the crack, displacement and maximum shear force.
2. The value of lateral force depended of the tensile strength of reinforcement and yield strength of reinforcement, if tensile strength of reinforcement and yield strength of reinforcement high the lateral force would be high, vice versa.
3. Value of bond stress-slip embedded bars depended of transverse reinforcement ratio and confining pressure of reinforcement.
4. From the calculated the value of confinement pressure interior beam-column joint (0.186).
5. The predicted failure mechanisms and crack patterns for the simulation VecTor2 use bond stress-slip also showed good correlation with the experimental test results.

References

[1] Chak, I. and Vecchio, F. J. (2013). User's Manual of Janus. Online Publication, 211 pp. <http://www.civ.utoronto.ca/vector/user_manuals/manual5.pdf>.
[2] Darwin, D., Nilson, A., Dolan, C. (2003). Design of Concrete Structures, Thirteenth Edition, New York.
[3] Eligehausen, R., Sharma, A., and Reddy, G.R. (2010). A New Model to Simulate Joint Shear Behavior of Poorly Detailed Beam-Column Connections in RC Structures Under Seismic Load, Part I: Exterior Joints. Engineering Structures, 2010.12.026.
[4] Eom, T.S., Hwang, H.J., Park, H.G. (2015). Design considerations for interior RC beam–column joint with additional bars. Engineering Structures, 98 (2015) 1–13.
[5] Gan, Y. (2000). Bond Stress and Slip Modeling in Nonlinear Finite Element Analysis of Reinforced Concrete Structures, Master Thesis, Department of Civil Engineering, University of Toronto, 251 pp.
[6] Guner, S. and Vecchio, F.J. (2008). User's Manual of VecTor5. Online Publication, 88 pp.

[7] Guner, S. and Vecchio, F. J. (2011). Analysis of Shear-Critical Reinforced Concrete Plane Frame Elements under Cyclic Loading. Journal of Structural Engineering, American Society of Civil Engineers, V.137, No.8, pp. 834-843.

[8] Guner, S. and Vecchio, F. J. (2010). Pushover Analysis of Shear-Critical Frames: Verification and Application. American Concrete Institute Structural Journal, V.107, No.1, pp. 72-81.

[9] Lowes, L.N. and Alttontash, A. (2003). Modeling Reinforced Concrete Beam-Column Joints Subjected to Cyclic Loading. J. Strut. Eng. 129(12), 1686-1697.

[10] Mitra, N. Lowes, L.N. (2007). Evaluation, Calibration, and Verification of a Reinforced Concrete Beam–Column Joint Model. Journal of Structural Engineering © ASCE / January, 2007.

[11] Pan, Z. (2016). Modeling of Interior Beam-column Joints for Nonlinear Analysis of Reinforced Concrete Frames. Master Thesis, Department of Civil Engineering, University of Toronto, 177 pp.

[12] Sadeghian, V. and Vecchio, F.J. (2014). User's Manual of Cyrus. Online Publication, 44 pp.

[13] Shiohara, H. and Kusuhara, F. (2008). Tests of R/C Beam-Column Joint with Variant Boundary Conditions and Irregular Details on Anchorage of Beam Bars. 14th World Conf. on Earthquake Engineering, Beijing, China.

[14] Zhang, P., Hou, S., Ou, J. (2016). A Beam-Column Joint Element for Analysis of Reinforced Concrete Frame. Journal Engineering Structure, 118 (2016) 125-136

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