Appendix

Calculation of nominal strength for the experimental study

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Before producing the test specimens, the concrete elements such as beam, column and joint need to be calculated the strength capacities, to explore the weakest element, location and failure mode. The test specimens were the seven 2/3 scaled cruciform shaped interior beam-column subassemblies as shown in Figure A-1, composing of one monolithic and six precast connections. The designs of the test specimens were based on the strong column–weak beam design philosophy in correspondence with the seismic design code ACI 318-14 and the ACI 352R-02(2002) for the concrete elements and joint detailing on moderate seismic regions. For the structural detailing, it is shown in Table A-1, also described in the chapter 3.

To calculate the nominal capacity of each structural element, equations (A-1) and (A-2) according to ACI 318-14 were used to calculate the nominal moment (M_n) and shear (V_n), respectively. However, the yield strength (f_y) of longitudinal reinforcement was decreased to 0.50 times where the lap-splices were installed in the precast specimens. The nominal shear strengths of the joint calculated from equation (A-3) are shown in Table 4, according to ACI 352R-02. Table A-2 shows the Section detailing and nominal capacities of structural elements. To predict the failure mode of each concrete specimen during testing, the structural indices are used for the predicting, as shown in Table A-3 and Table A-5. For the index of nominal moment to nominal shear capacity ratio (M_n/a_bV_n), the index exhibits a possibility of mode failure. The index larger than 1.0 shows higher nominal flexural strength compared with shear strength, meaning that the shear failure will occur before flexural failure. Table A-6 shows the expectation of maximum story shear, failure mode and failure element.

Table A-1 Reinforcement detailing of test specimens

<table>
<tr><th rowspan="3">Specimens</th><th colspan="4">Beam</th><th colspan="3">Column</th></tr>
<tr><th rowspan="2">Dimension (b_b x h_b) (*mm*)</th><th colspan="2">Longitudinal bars</th><th rowspan="2">Transverse bar</th><th rowspan="2">Dimension (b_c x h_c), (*mm*)</th><th rowspan="2">Longitudinal bars</th><th rowspan="2">Transverse bar</th></tr>
<tr><th>Top</th><th>Bottom</th></tr>
<tr><td>M1</td><td rowspan="7">150 × 300</td><td>4-DB12</td><td>3-DB12</td><td rowspan="7">RB6 @ 65 mm</td><td rowspan="7">200 × 300</td><td>10-DB12</td><td rowspan="7">RB6 @ 65 mm</td></tr>
<tr><td>P1</td><td rowspan="4">4-DB12 (lap-splices)</td><td rowspan="5">T-section with lap-splices</td><td rowspan="6">4-DB25</td></tr>
<tr><td>P2</td></tr>
<tr><td>P3</td></tr>
<tr><td>P4</td></tr>
<tr><td>P5</td><td>T-section with lap-splices</td></tr>
<tr><td>P6</td><td>T-section without lap-splices</td><td>T-section without lap-splices</td></tr>
</table>

The nominal flexural strength (SI unit) of the beam and column is,

$$M_n = \rho f_y b d^2 (1 - 0.59 \frac{\rho f_y}{f'_c}) \quad (A\text{-}1)$$

The nominal shear strength (SI unit) of the beam and column is,

$$V_n = V_{n(concrete)} + V_{n(stirrup)} \quad (A\text{-}2)$$

$$V_{n(concrete)} = 0.17\sqrt{f_c'}bd \quad (A\text{-}2\text{-}a)$$

$$V_{n(stirrup)} = \frac{A_v f_{y(stirrup)} d}{S} \quad (A\text{-}2\text{-}b)$$

The nominal shear strength (SI unit) of the precast column is

$$V_n = 0.40 F_y A_{st} \quad (A\text{-}2)$$

Where ρ is a tension reinforcement ratio (A_s/bd), A_s is a section area of tension reinforcement, A_s is a section area of transverse reinforcement, b is a width of concrete member, d is a distance from extreme compression fiber to centroid of longitudinal tension reinforcement, f'_c is a specified compressive strength of concrete, f_y is a specified yield strength of longitudinal reinforcement, and $f_{y(stirrup)}$ is a specified yield strength of transverse reinforcement

$$V_n = 0.083\gamma\sqrt{f_c'}b_jh_c \qquad (A\text{-}3)$$

Where b_j is the effective joint width, h_c is the depth of the column in consideration to the direction of the joint shear and γ–values for type 2 connections depending on the connection classification as defined in ACI 352R-02-chapter 4 as shown in Figure A-2.

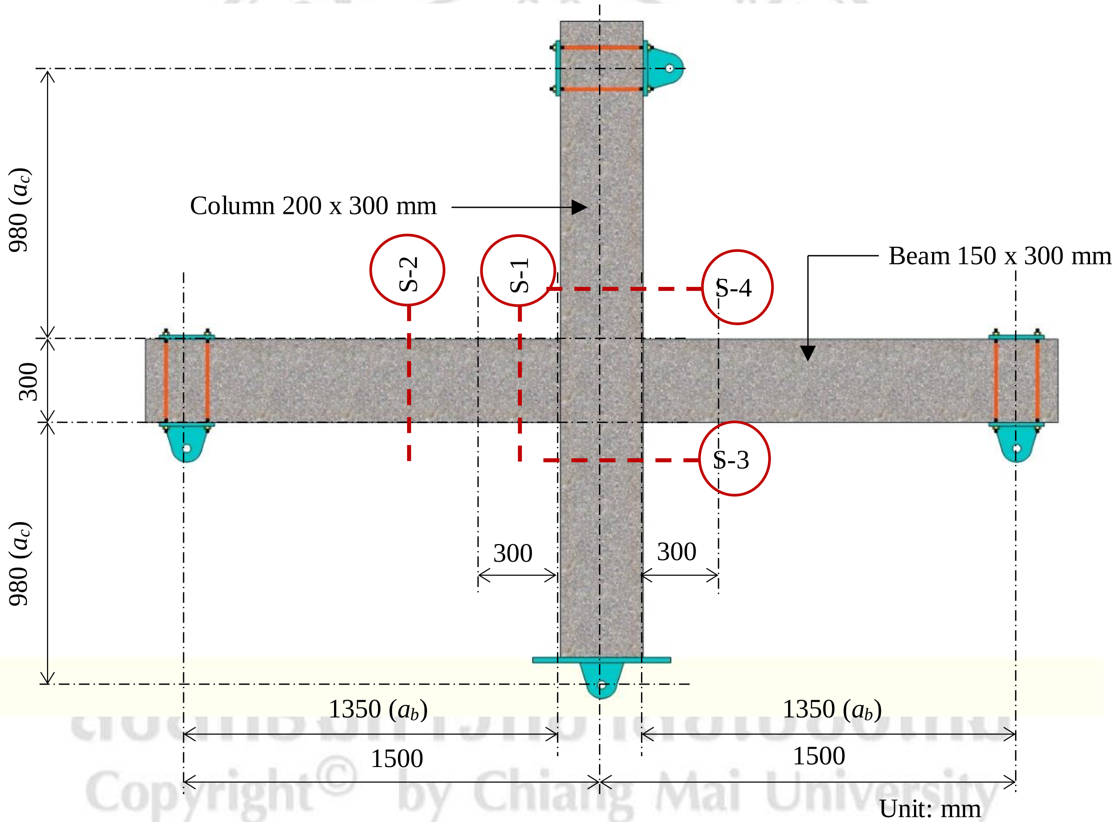


Figure A-1 Test specimen dimension

Table A-2 Section details and nominal capacities of structural elements

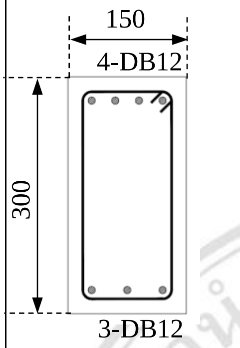
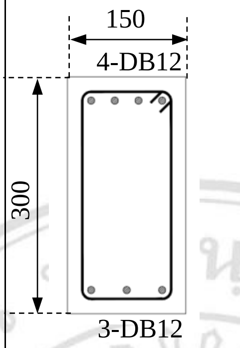
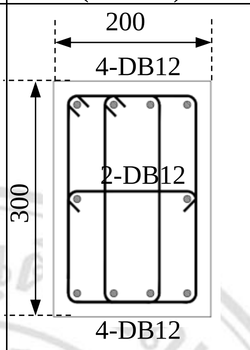
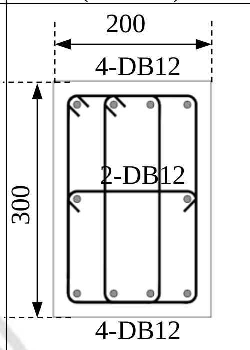
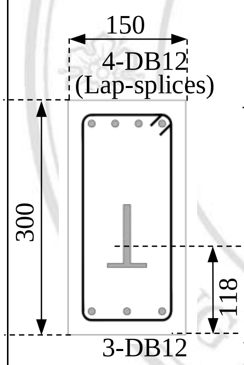
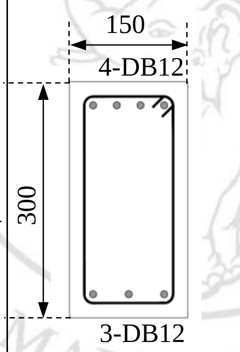
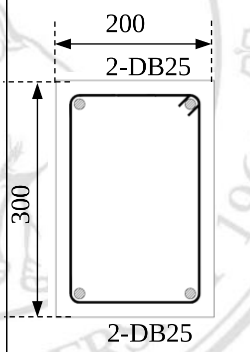
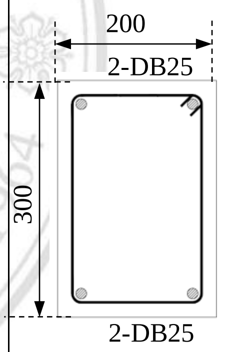
Specimens	Sectional Location			
	S-1 (Beam)	S-2 (Beam)	S-3 (Column)	S-4 (Column)
M1	 M_n^+ = 44 kN-m M_n^- = 56 kN-m V_n = 121 kN	 M_n^+ = 44 kN-m M_n^- = 56 kN-m V_n = 121 kN	 M_n^+ = 67 kN-m M_n^- = 67 kN-m V_n = 215 kN	 M_n^+ = 67 kN-m M_n^- = 67 kN-m V_n = 215 kN
P1	 M_n^+ = 42 kN-m (42 kN-m, bond-slip) M_n^- = 53 kN-m (34 kN-m, bond-slip) V_n = 121 kN	 M_n^+ = 44 kN-m M_n^- = 56 kN-m V_n = 121 kN	 M_n^+ = 99 kN-m M_n^- = 99 kN-m V_n = 135 kN	 M_n^+ = 99 kN-m M_n^- = 99 kN-m V_n = 135 kN

Table A-2 (Continue) Cross-section details and nominal capacities of structural elements

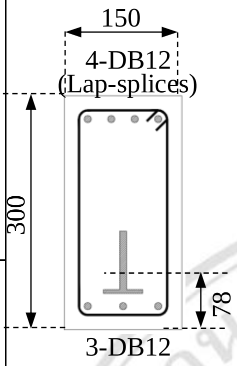
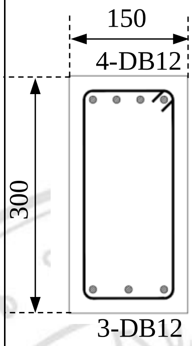
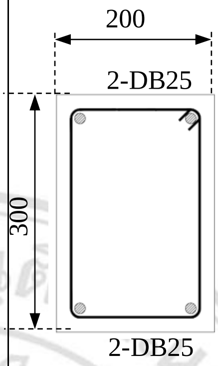
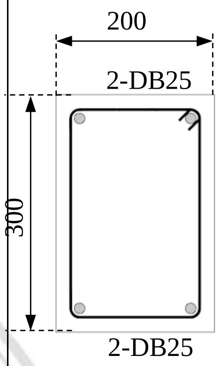
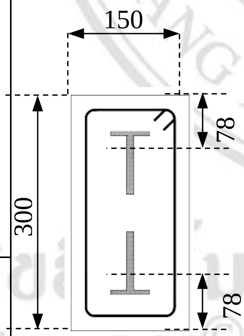
Specimens	Sectional Location			
	S-1 (Beam)	S-2 (Beam)	S-3 (Column)	S-4 (Column)
P2 P3 P4	 M_n^+ = 52 kN-m (52 kN-m, bond-slip) M_n^- = 53 kN-m (34 kN-m, bond-slip) V_n = 121 kN	 M_n^+ = 44 kN-m M_n^- = 56 kN-m V_n = 121 kN	 M_n^+ = 99 kN-m M_n^- = 99 kN-m V_n = 135 kN	 M_n^+ = 99 kN-m M_n^- = 99 kN-m V_n = 135 kN
P5 P6	 M_n^+ = 55 kN-m M_n^- = 55 kN-m V_n = 121 kN			

Table A-3 Structural indices (Beam)

Specimen	Clear span, a_b (m)	Shear span ratio $\frac{a_b}{h_b}$	M_n^+ (kN-m)	M_n^- (kN-m)	V_n (kN)	$\frac{M_n^+}{a_b V_n}$	$\frac{M_n^-}{a_b V_n}$	$R_{\max}$ (kN)	Strength $H_{b-\max}$ (kN)
M1	1.35	4.50	44	56	121	0.269	0.343	32.59	43.25
P1	1.35	4.50	42	53	121	0.257	0.386	31.11	41.28
P2	1.35	4.50	52	53	121	0.318	0.324	38.52	51.11
P3	1.35	4.50	52	53	121	0.318	0.324	38.52	51.11
P4	1.35	4.50	52	53	121	0.318	0.324	38.52	51.11
P5	1.35	4.50	55	55	121	0.337	0.337	40.74	54.06
P6	1.35	4.50	55	55	121	0.337	0.337	40.74	54.06

Table A-4 Structural indices (Beam, bond-slip consideration)

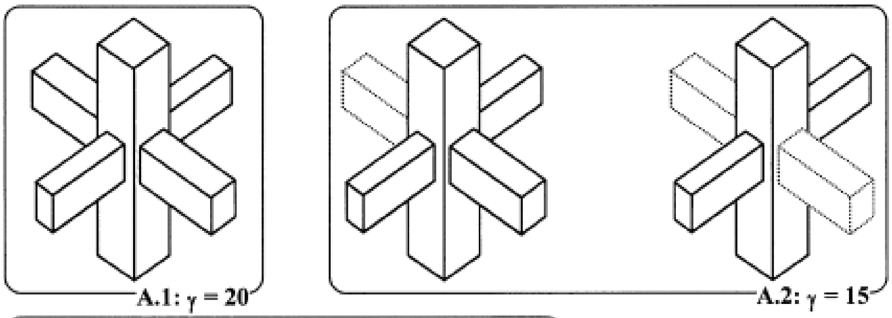
Specimen	Clear span, a_b (m)	Shear span ratio $\frac{a_b}{h_b}$	M_n^+ (kN-m)	M_n^- (kN-m)	V_n (kN)	$\frac{M_n^+}{a_b V_n}$	$\frac{M_n^-}{a_b V_n}$	$R_{\max}$ (kN)	Strength $H_{b-\max}$ (kN)
P1	1.35	4.50	42	34	121	0.318	0.208	25.19	33.42
P2	1.35	4.50	52	34	121	0.318	0.208	25.19	33.42
P3	1.35	4.50	52	34	121	0.318	0.208	25.19	33.42
P4	1.35	4.50	52	34	121	0.318	0.208	25.19	33.42

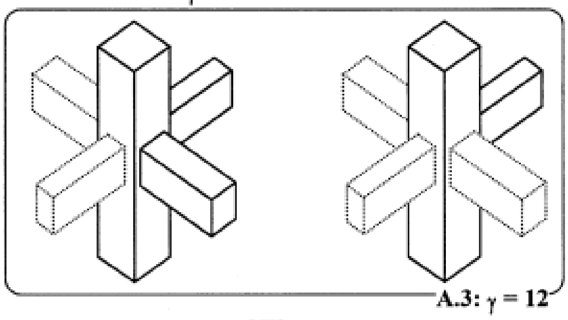
Table A-5 Structural indices (Column and Beam-column joint)

Specimen	Column						Beam-column joint		
	Clear span, a_c (mm.)	Shear span ratio $\frac{a_c}{h_c}$	M_n (kN-m)	V_n (kN)	$\frac{M_n}{a_c V_n}$	Strength $H_{c-\max}$ (kN)	γ	b_j (mm.)	Strength $H_{j-\max}$ (kN)
M1	980	3.27	67	215	0.334	68.37	15	200	495.67
P1	980	3.27	99	136	0.743	101.02	15	200	564.12
P2	980	3.27	99	136	0.743	101.02	15	200	564.12
P3	980	3.27	99	136	0.743	101.02	15	200	564.12
P4	980	3.27	99	136	0.743	101.02	15	200	564.12
P5	980	3.27	99	136	0.743	101.02	15	200	564.12
P6	980	3.27	99	136	0.743	101.02	15	200	564.12

Table A-6 Summary the maximum story shear and failure mode of test specimen

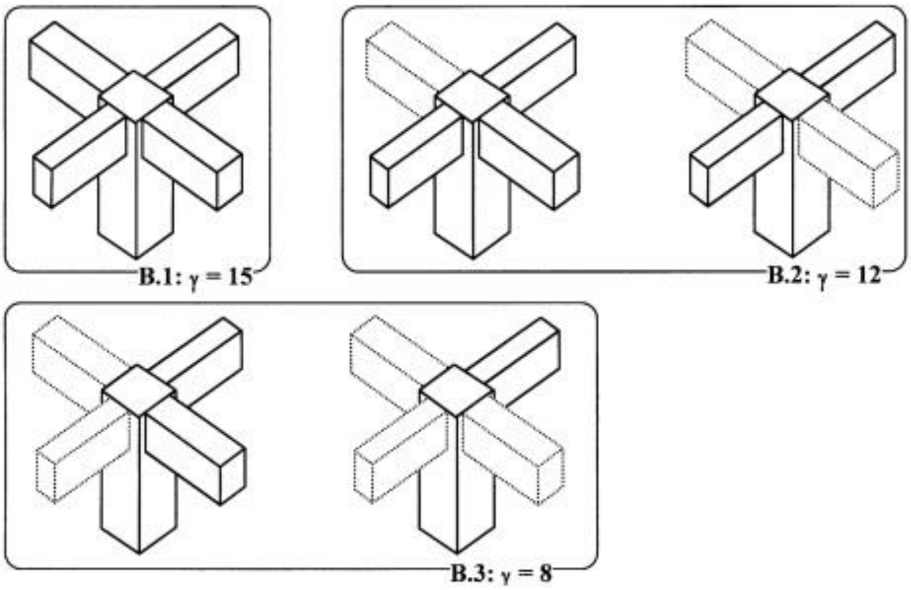
Specimen	Shear strength, *H*(kN)				Expected maximum Strength, H_{expect} (kN)	Failure Mode	Failure Member
	Beam	Beam (Bond-slip)	Column	joint			
M1	43.25	-	68.37	495.67	43.25	Flexural Failure	Beam
P1	41.28	33.42	101.02	564.12	33.42	Bond Failure	Beam
P2	51.11	33.42	101.02	564.12	33.42	Bond Failure	Beam
P3	51.11	33.42	101.02	564.12	33.42	Bond Failure	Beam
P4	51.11	33.42	101.02	564.12	33.42	Bond Failure	Beam
P5	54.06	-	101.02	564.12	54.06	Flexural Failure	Beam
P6	54.06	-	101.02	564.12	54.06	Flexural Failure	Beam





Note: Dashed lines represent either a frame member that does not exist or a member whose width is less than three-quarter of the width of the column or its total depth is less than three-quarter of the total depth of the deepest member framing into the joint

(a) Case A: Two columns framing into the joint



(b) Case B: One columns framing into the joint

Figure A-2 γ–values for type 2 connections

(ACI 352R-02, 2002)

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Ketiyot, R. , Hansapinyo, C. and Chaimahawan, P. (2012) “Test Of Exterior Precast Concrete Beam-Column Frame with Bolted Connection Under Cyclic Loading” Proceedings of the Seventeenth National Convention on Civil Engineering, The Engineering Institute of Thailand(NCCE17), Thailand. 9-11 May 2012. (In Thai).

Ketiyot, R. and Hansapinyo, C. (2012) “Cyclic Behavior of Exterior Precast Concrete Beam Column Frames Using Combined Welded-Bolted Connection” Proceeding of the First International Conference on Performance-based and Life-cycle Structural Engineering (PLSE 2012), Hong Kong, 5-7 December 2012

Ketiyot, R. and Hansapinyo, C. (2013) "Tests of Interior Concrete Beam-Column Frames with Debonded Rebars Under Cyclic Loading" Proceedings of the Eighteenth National Convention on Civil Engineering, The Engineering Institute of Thailand, Chiang Mai(NCCE18), Thailand. 8-10 May 2013. (In Thai).

Ketiyot, R. and Hansapinyo, C. (2014) " Precast Concrete Beam-Column Interior Joint with Stirrups under Cyclic Loading " Proceedings of the Nineteenth National Convention on Civil Engineering, The Engineering Institute of Thailand, Khon Kaen (NCCE19), Thailand. 8-10 May 2014. (In Thai)

Kettiyot, R. and Hansapinyo, C. (accepted) "Seismic Performance of Interior Precast Concrete Beam-Column Connections with T-Section Steel Inserts Under Cyclic Loading", Earthquake Engineering and Engineering Vibration.

Kettiyot, R. and Hansapinyo, C. (accepted) "Seismic Performance of Reinforced Concrete Interior Frames Using Super Ductile Reinforcing Steel Bar", Engineering Journal Chiang Mai University.