Structural Performance of Precast and Cast-in-Place Composite Concrete Beams with Dapped End

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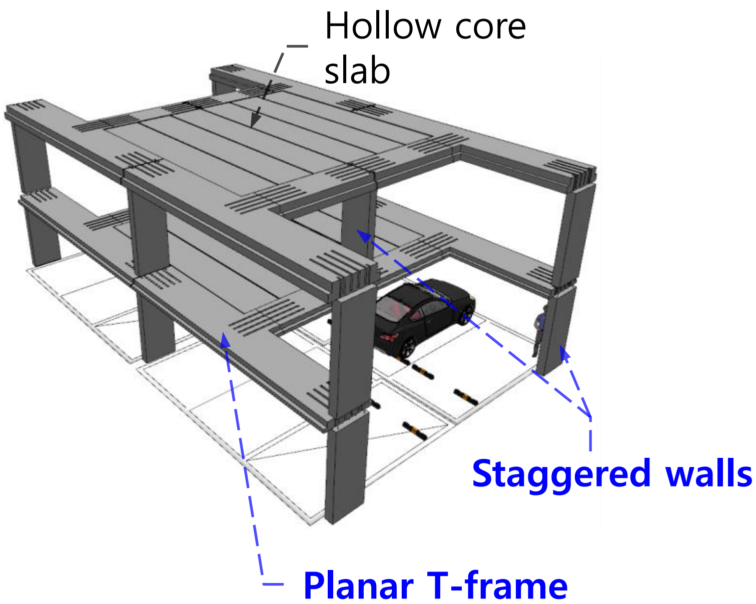
Contents

(1) Precast concrete T-frame floor system

- A gravity load-resisting system developed for underground parking garage

Concept



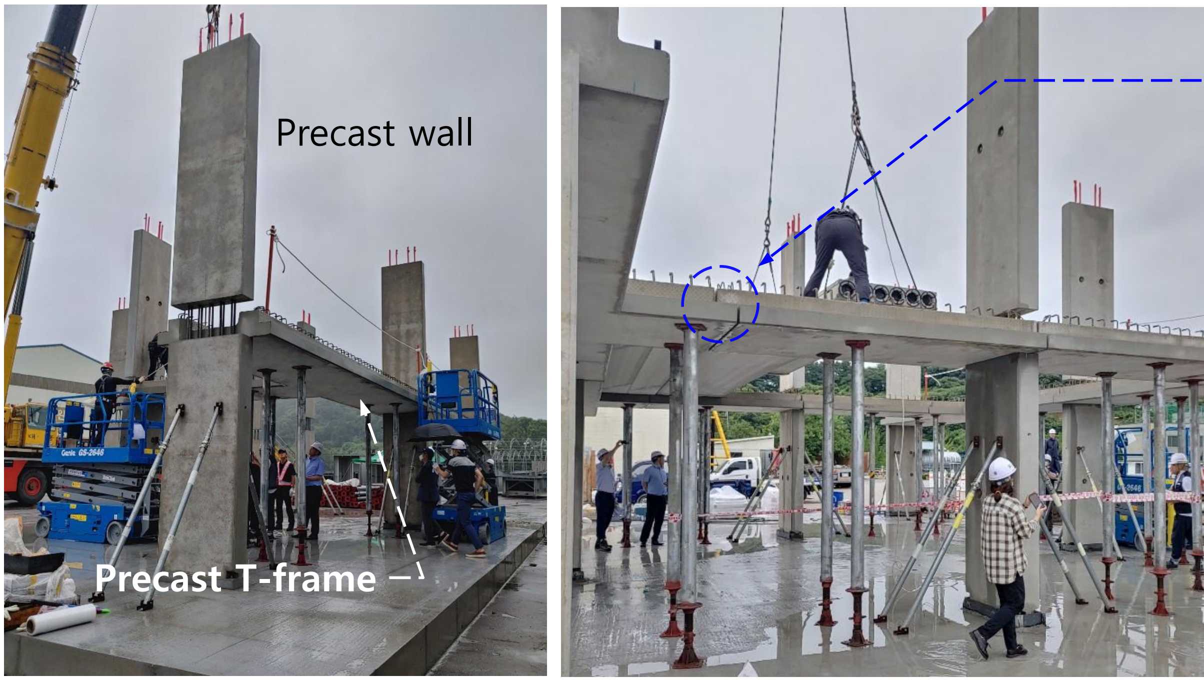
Mock-up test

1 Introduction

(1) Precast concrete T-frame floor system

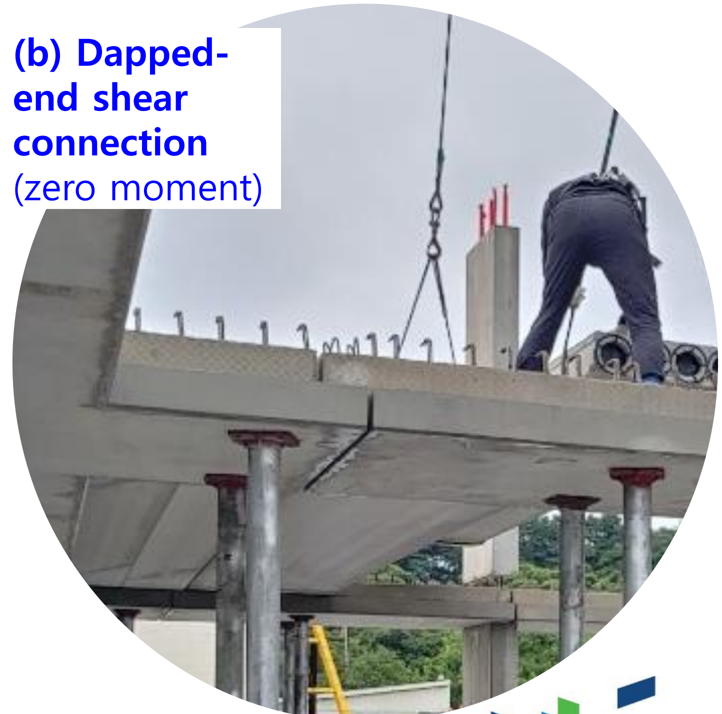
◆ A gravity load-resisting system developed for underground parking garage

Precast erection and connection



(a) T-frame floor for underground parking lot in apartment buildings

(b) Dapped-end shear connection
(zero moment)

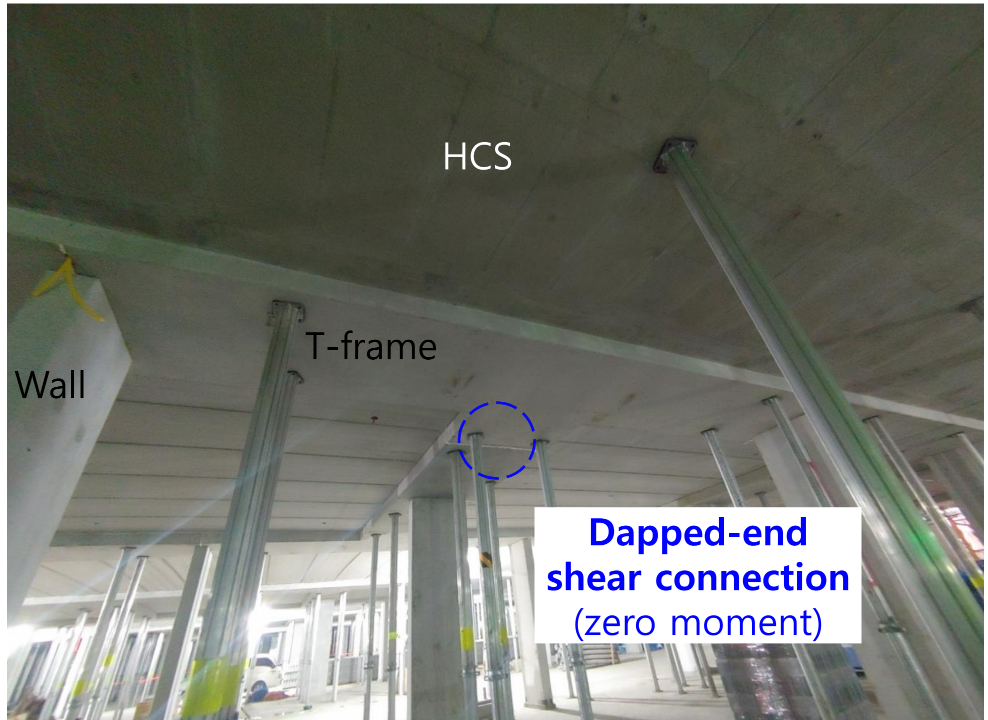


1 Introduction

(1) Precast concrete T-frame floor system

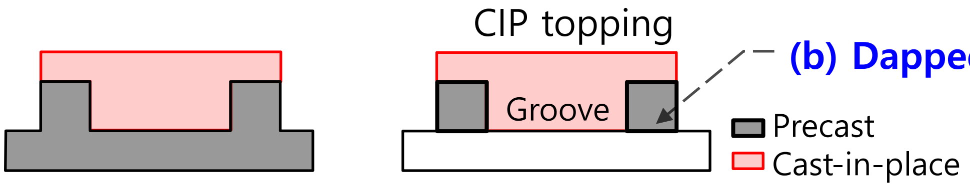
- A gravity load-resisting system developed for underground parking garage

Field construction (Incheon, Korea)



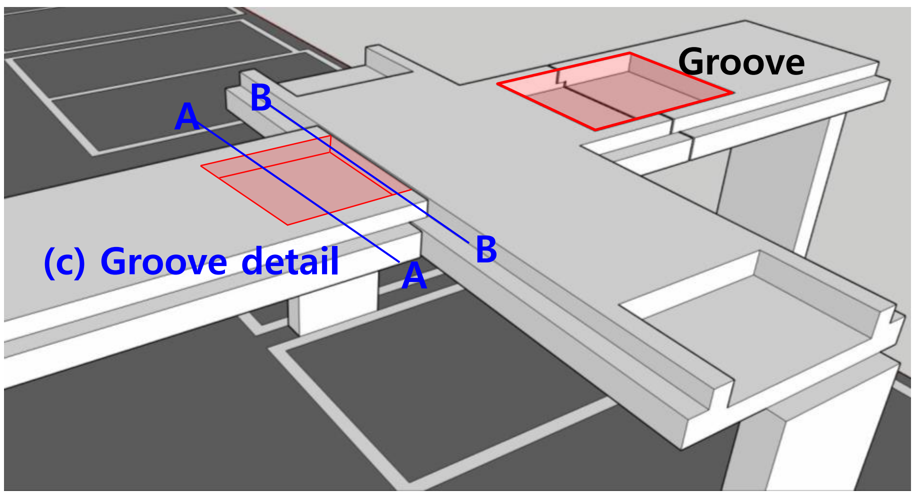
(2) Composite concrete dapped end with groove detail

- Groove detail to engage with precast elements



A-A section   B-B section

(b) Dapped end



(c) Groove detail

(a) Precast and CIP composite concrete

(3) Shear strengths of composite concrete beam

- Composite concrete section

$$V_n = V_c + V_s = 0.17\sqrt{f_c'}bd + A_v f_{yv}\frac{d}{s}$$

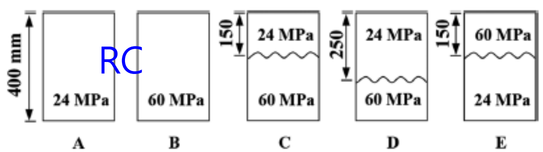
f_c' = precast? CIP? or their average?

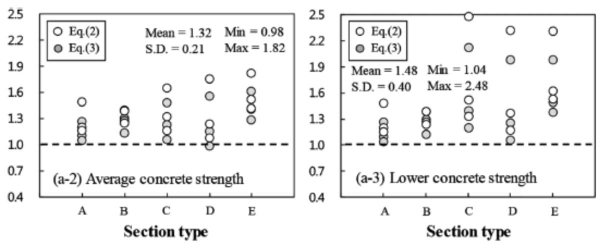
ACI STRUCTURAL JOURNAL TECHNICAL PAPER
Title No. 114-S67

Shear Strength of Concrete Composite Beams with Shear Reinforcements

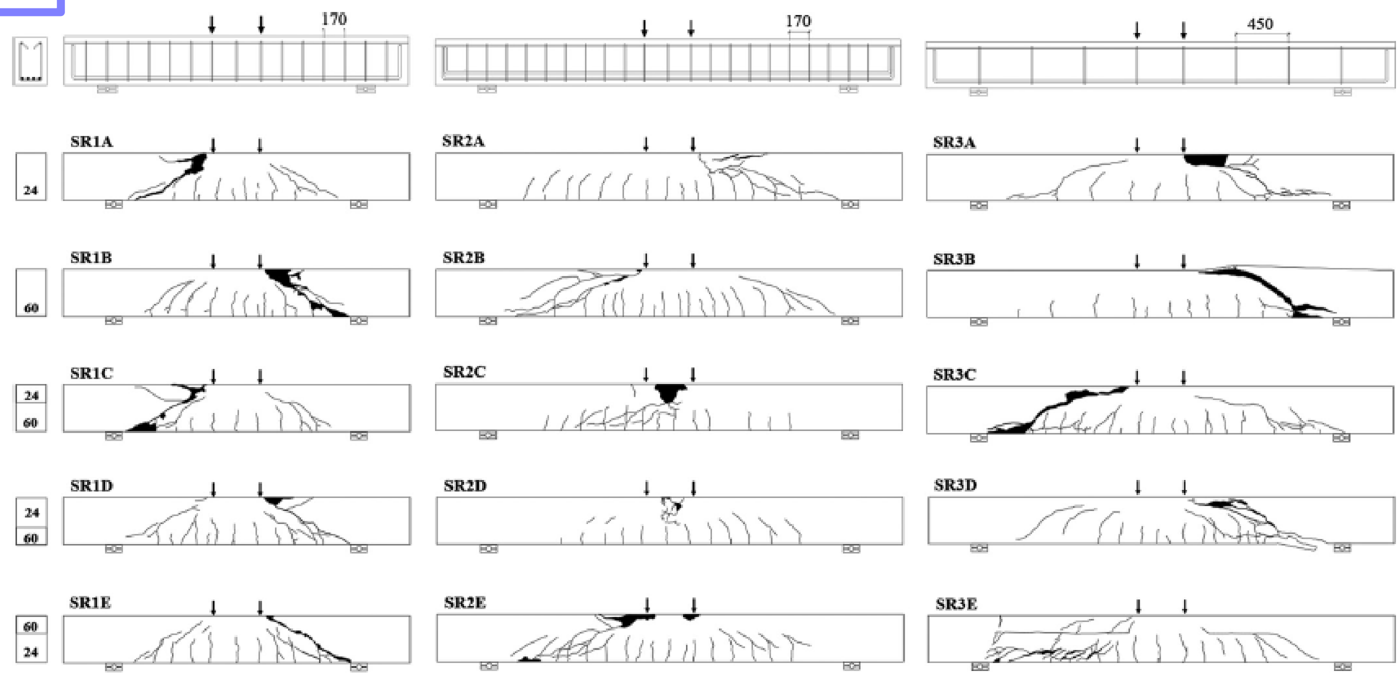
by Chul-Goo Kim, Hong-Gun Park, Geon-Ho Hong, Su-Min Kang, and Hyerin Lee

Composite beam of precast and CIP concrete





(a) ACI 318

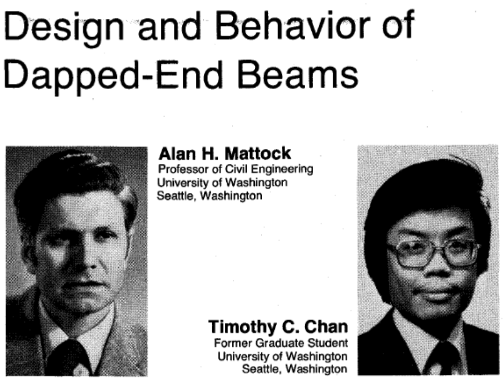


(a) SR1 (s = 170 mm, a/d = 2.5) (b) SR2 (s = 170 mm, a/d = 4.0) (c) SR3 (s = 450 mm, a/d = 4.0)

(3) Shear strengths of composite concrete beams with dapped end

- Composite concrete dapped end

Limit analysis along critical crack plane


Design and Behavior of Dapped-End Beams

Alan H. Mattock
Professor of Civil Engineering
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Former Graduate Student
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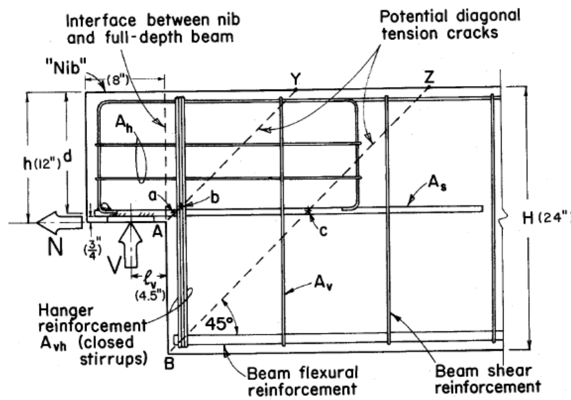


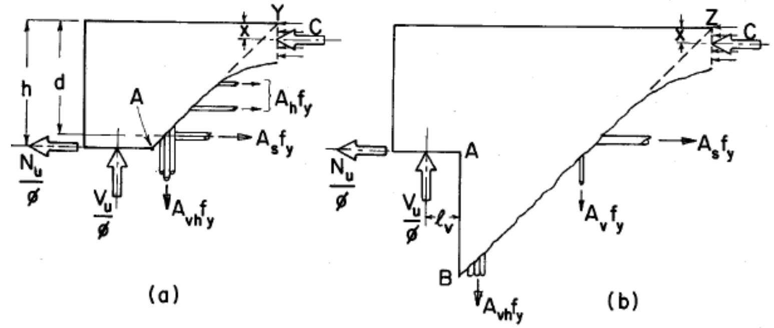


Fig. 3. Forces assumed acting on free bodies cut off by diagonal tension cracks in full-depth beam.

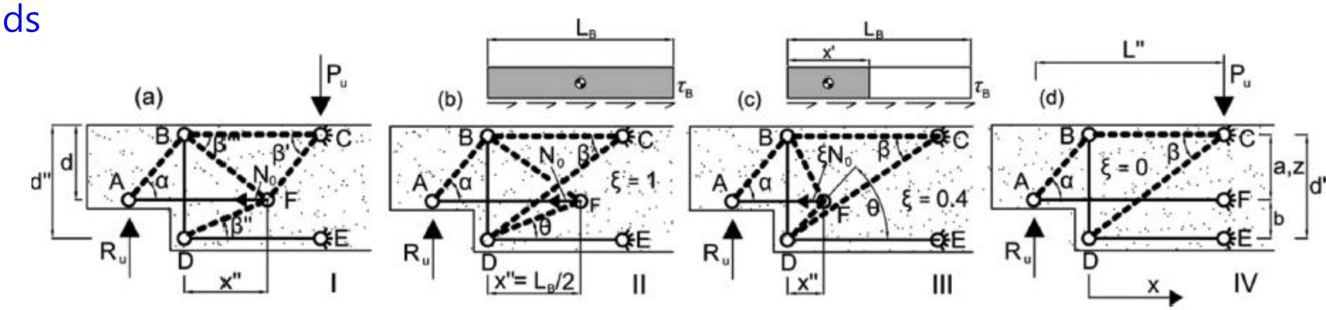
Strut-and-tie models of dapped ends


ACI STRUCTURAL JOURNAL

Title No. 116-S77

Bending and Shear Behavior in (
Reinforced Concrete Slabs

by Pietro G. Gambarova and Francesco Lo Monte

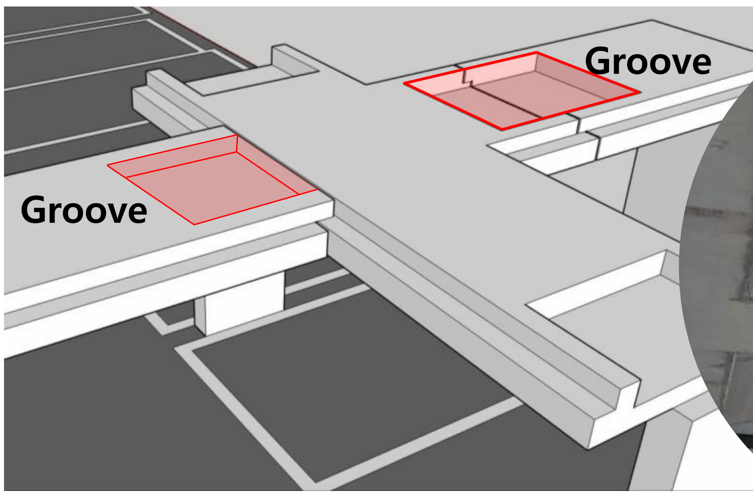


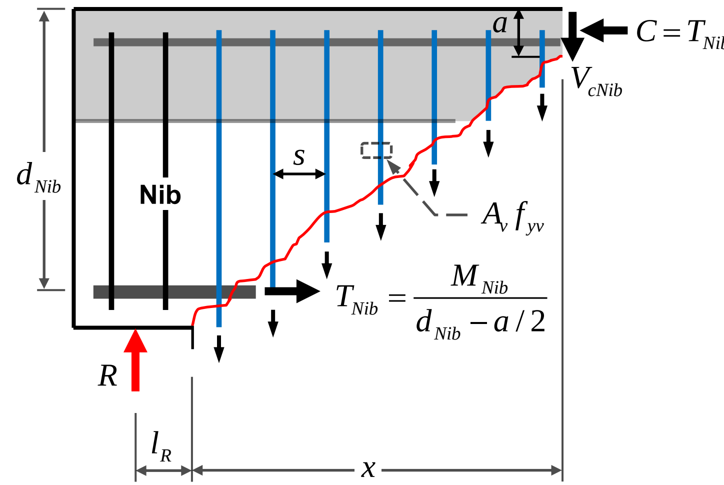
aci CONCRETE CONVENTION

1 Introduction

(4) Research objective

- Investigation of shear strengths of composite concrete beam
  - Composite section of precast and CIP concrete
  - Dapped ends with groove detail

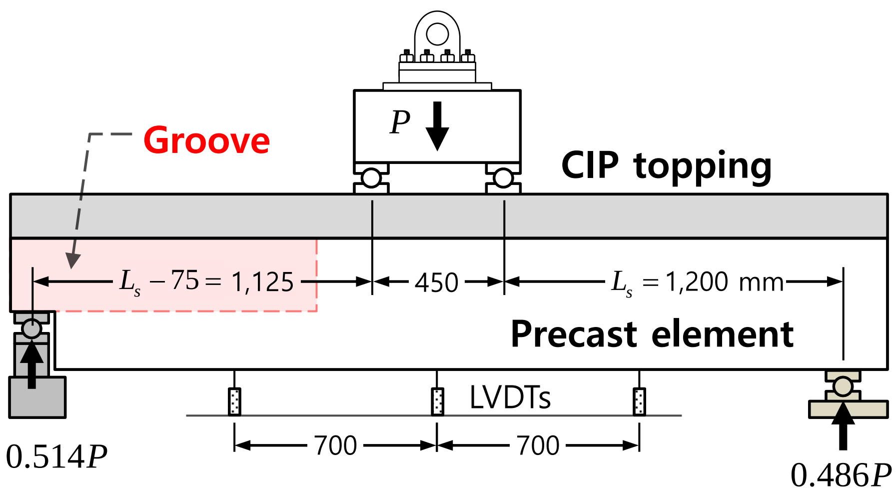


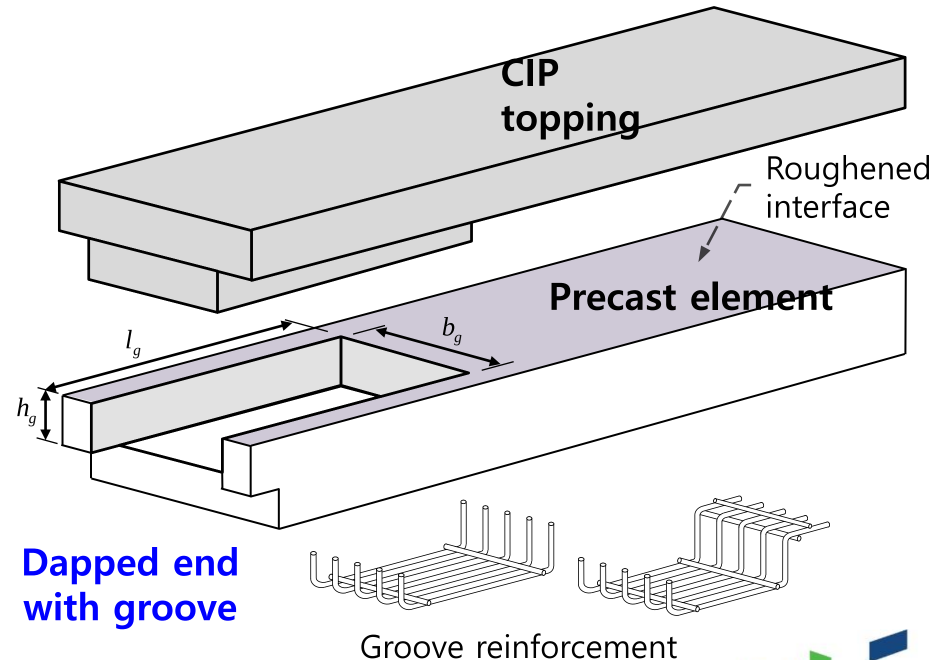


2 Experimental investigations

(1) Specimen details

- Composite concrete beam of precast element and CIP topping
- Simple beam with dapped end at one end
- Dapped end with groove details

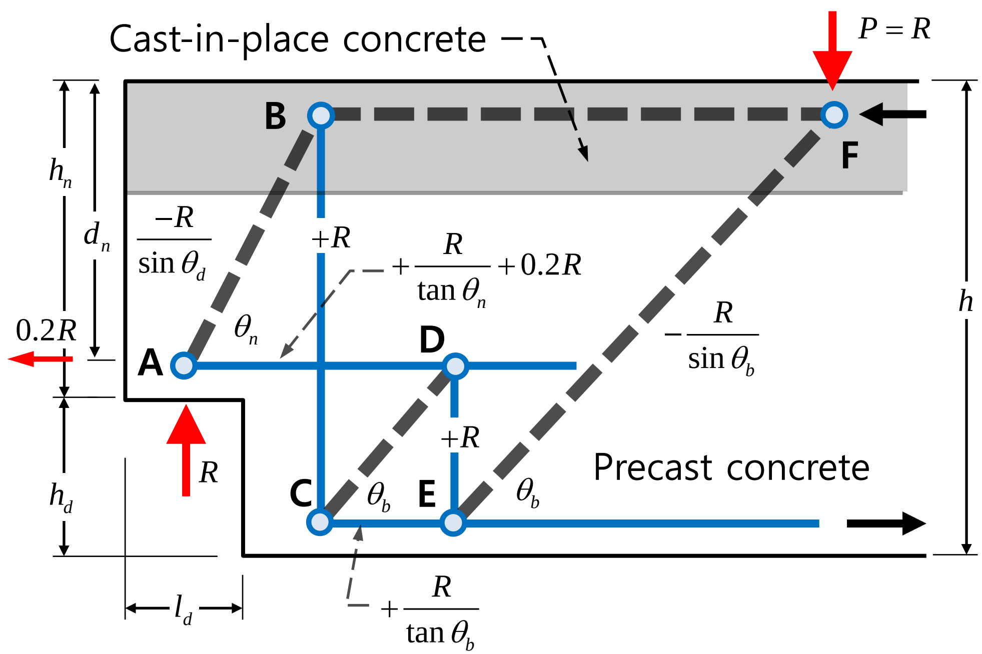




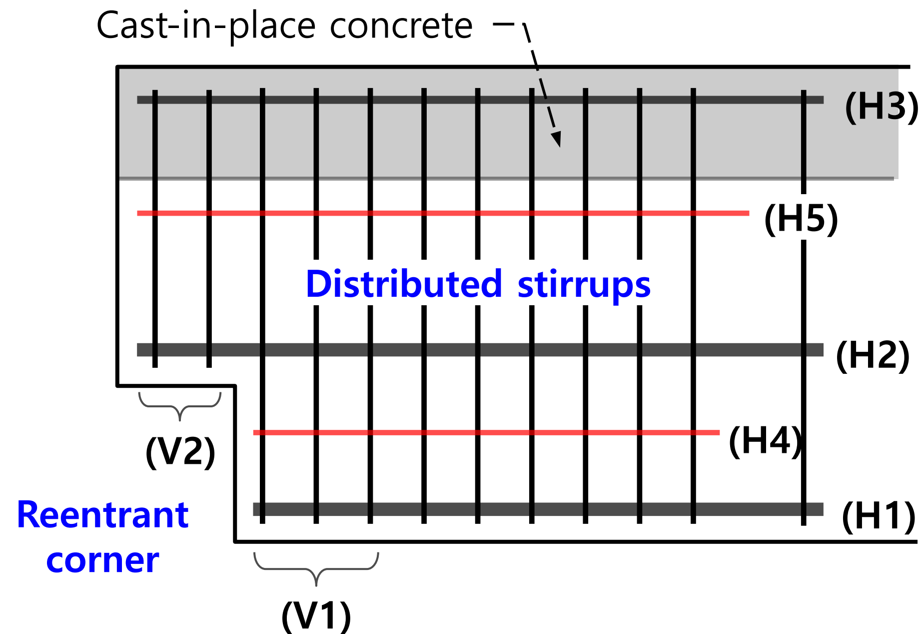
(1) Specimen details

◆ Structurally determinate strut-and-tie model used for design

Strut-and-tie model for shear design



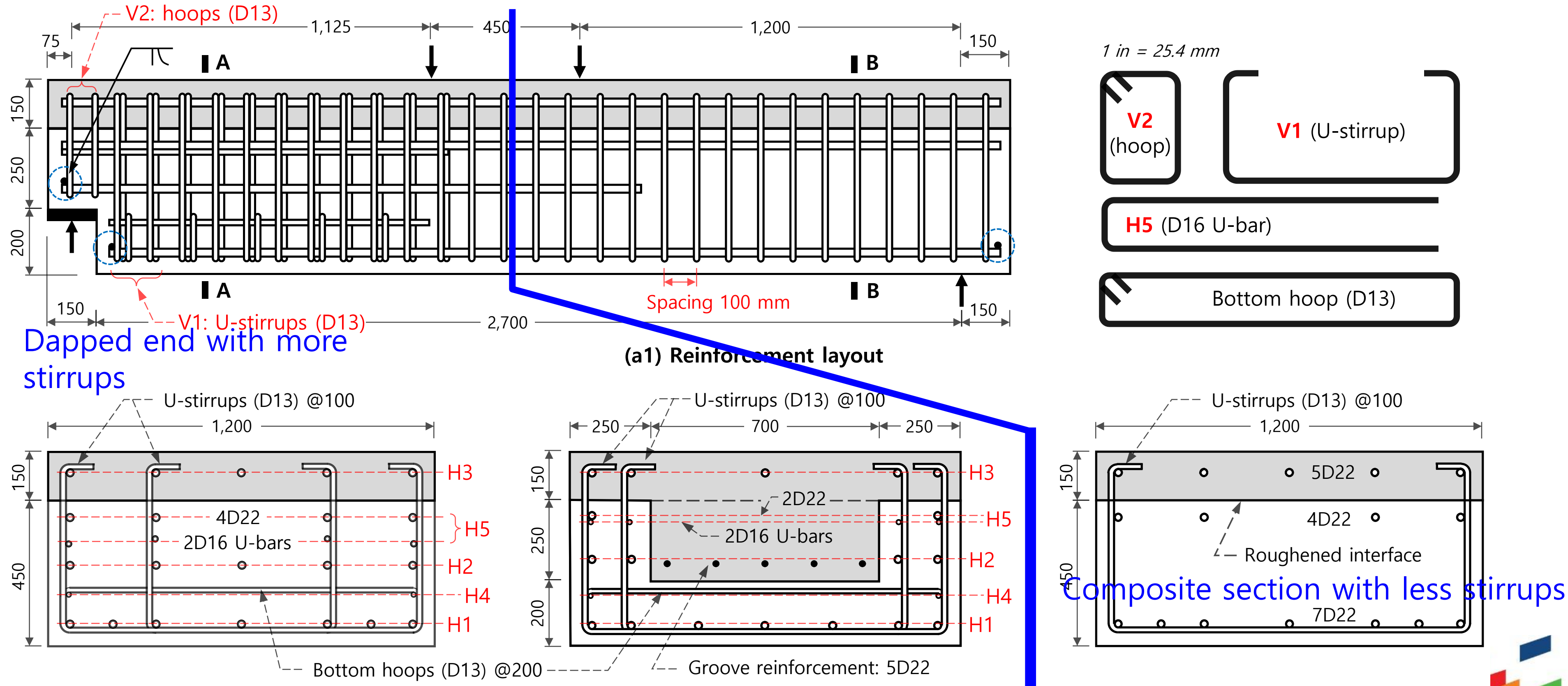
Reinforcement layout



2 Experimental investigations

(1) Specimen details

◆ Beam depth 600 mm = Precast 450 + CIP 150



(a1) Reinforcement layout

(a2) A-A section: #1 60-w/o G

(a3) A-A section: #2 60-G10-U and #3 60-G07-P

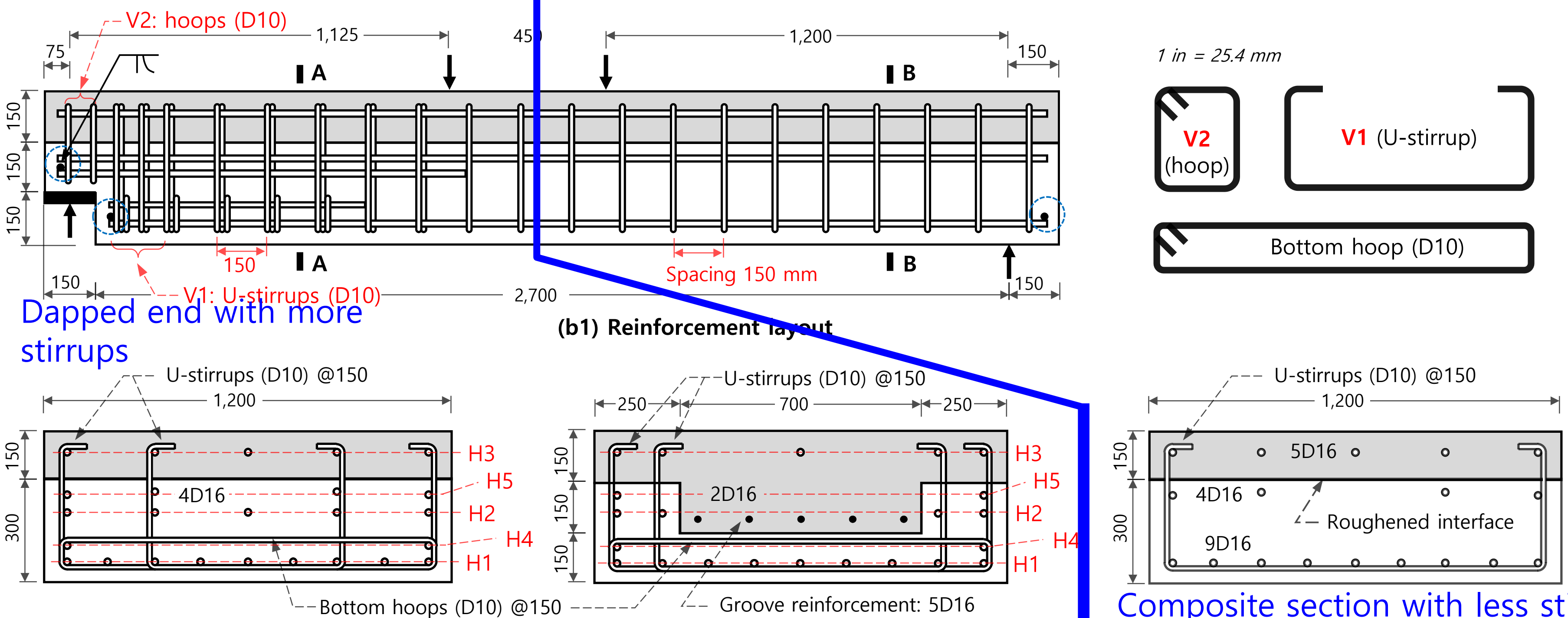
(a4) B-B section: all specimens

(a) Specimens #1 to #3 (composite section height = 600 mm)

2 Experimental investigations

(1) Specimen details

- Beam depth 450 mm = Precast 300 + CIP 150



(b2) A-A section: #4 45-w/o G

(b3) A-A section: #5 45-G08-U and #6 60-G05-P

(b4) B-B section: all specimens

(b) Specimens #4 to #6 (composite section height = 450 mm)

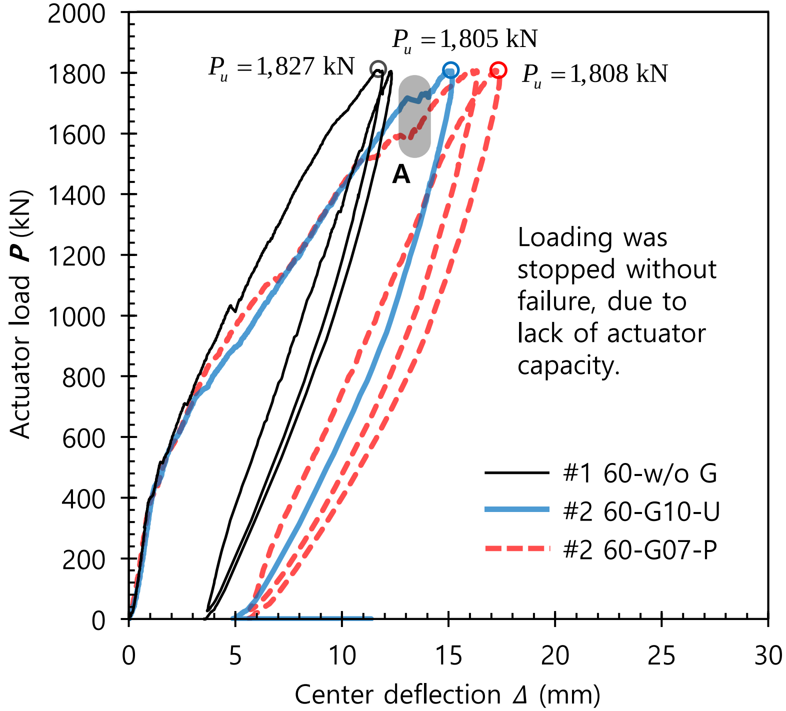
2 Experimental investigations

(2) Test results

- Beam depth 600 mm

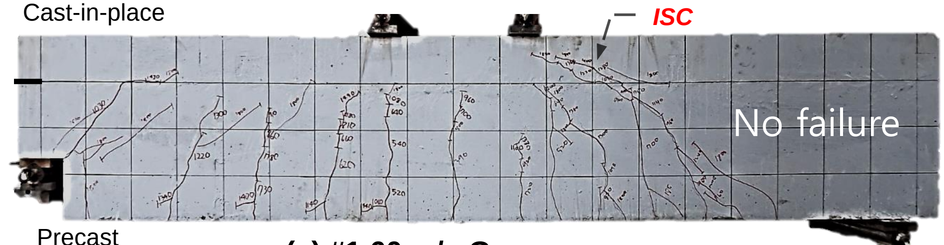
  = Precast 450 + CIP 150

Tests ended due to actuator's loading capacity (= 2,000 kN)



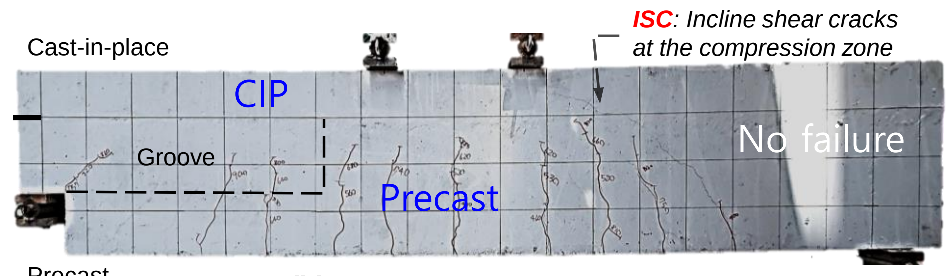
(a) Specimens #1 to #3 (composite section height = 600 mm)

No groove



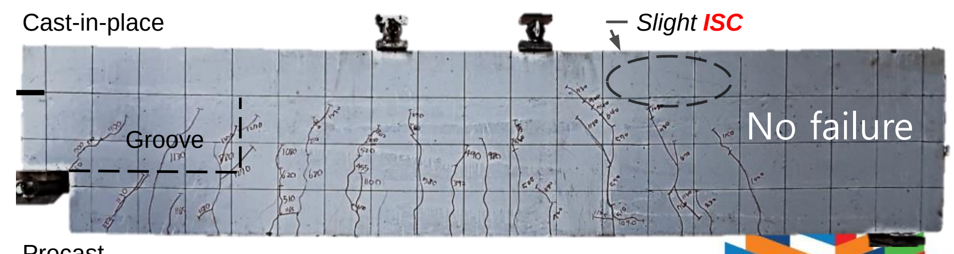
(a) #1 60-w/o G

Long groove



(b) #2 60-G10-U

Short groove

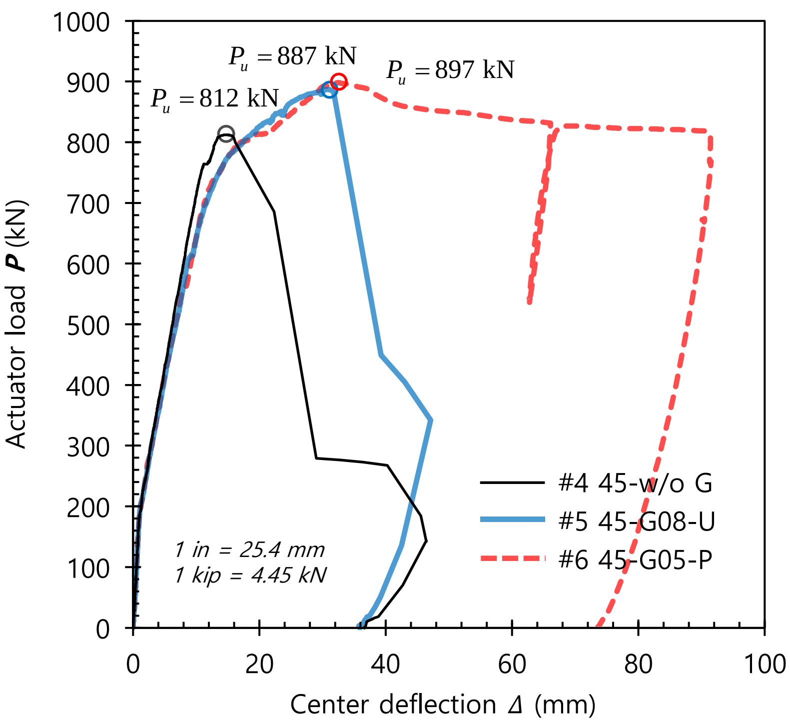


(c) #3 60-G07-P

(2) Test results

◆ Beam depth 450 mm

= Precast 300 + CIP 150



(b) Specimens #4 to #6 (composite section height = 450 mm)

Shear failure of composite beam section occurred at the right span without dapped ends

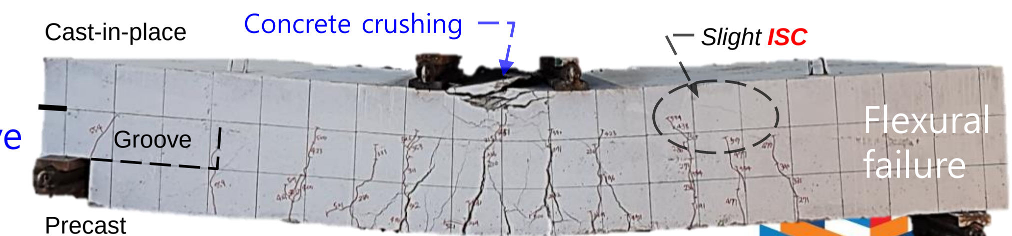
No groove

(d) #4 45-w/o G

Long groove

(e) #5 45-G08-U

Short groove



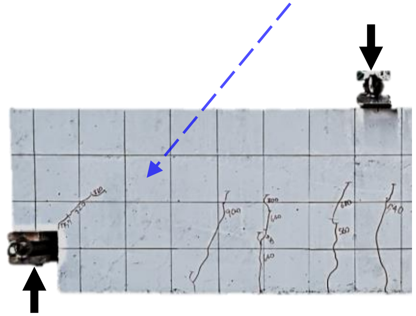
(f) #6 45-G05-P

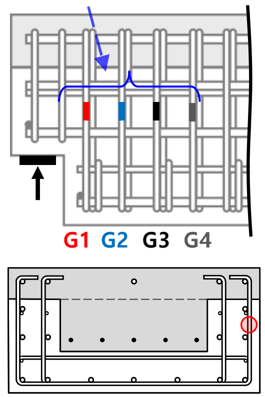
2 Experimental investigations

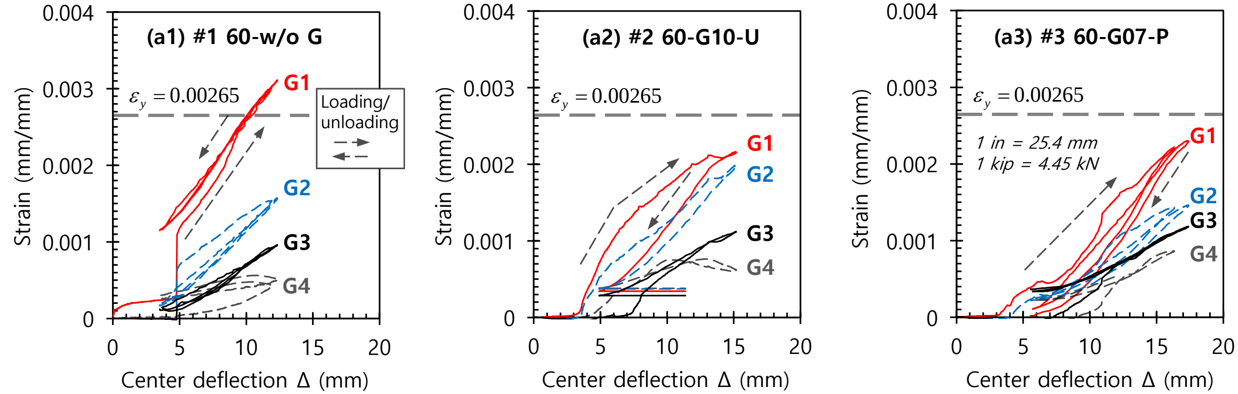
(2) Test results

- Stirrup strains

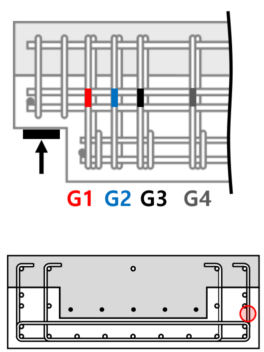
- Cracking from the reentrant corner.
- Although cracks are not obvious around the corner, the magnitudes of measured stirrup strains decrease as the distance from the corner increases.

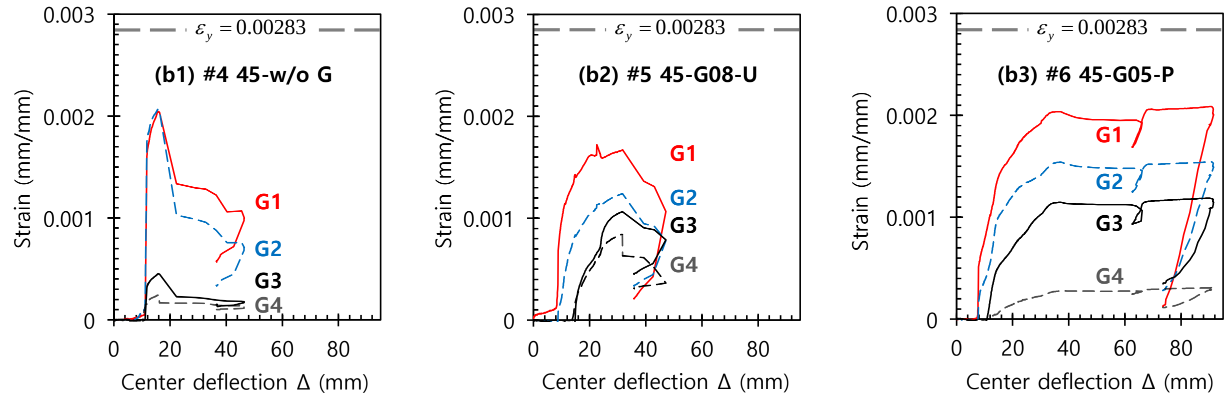






(a) Specimens #1 to #3 (composite section height = 600 mm)



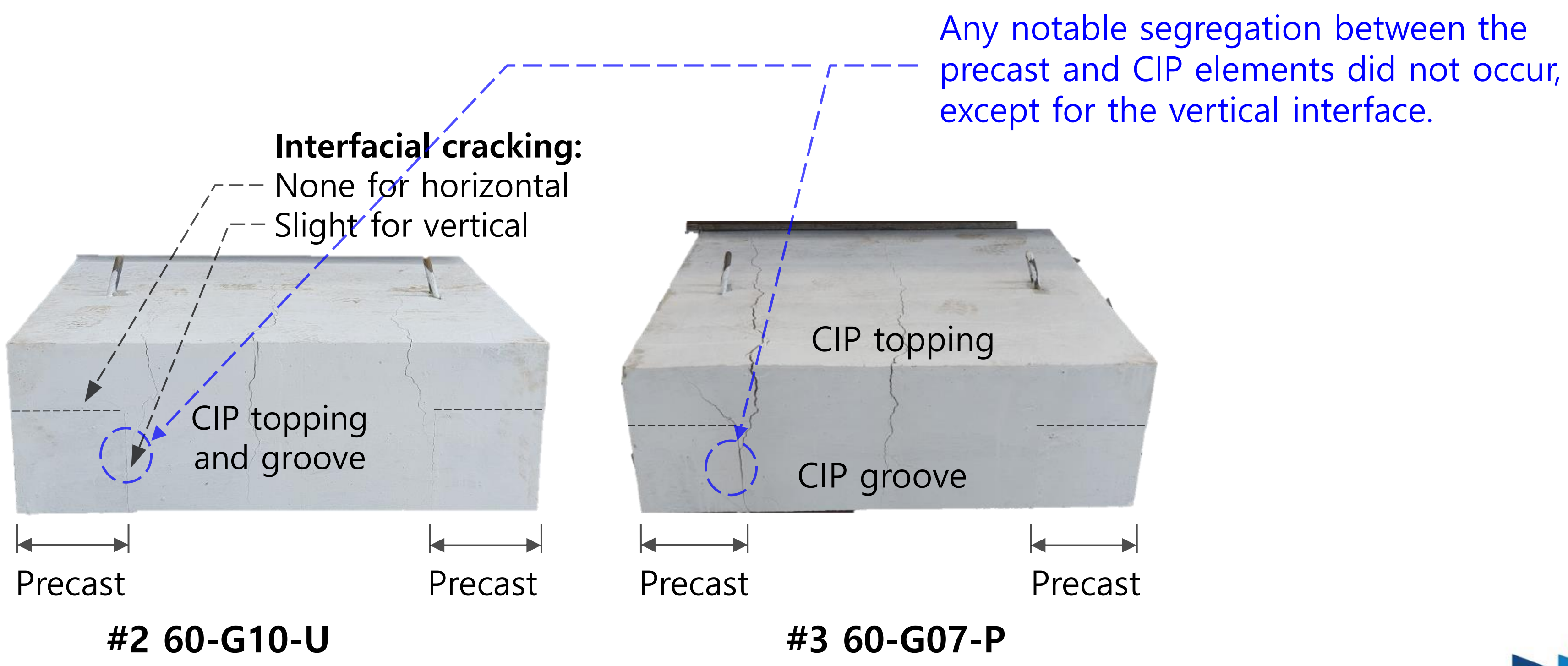


(b) Specimens #4 to #6 (composite section height = 450 mm)

3 Nominal strengths

(1) Flexural and shear strengths of composite concrete sections

- M_n and V_n of the composite sections were calculated using the **design theory for monolithic RC members**

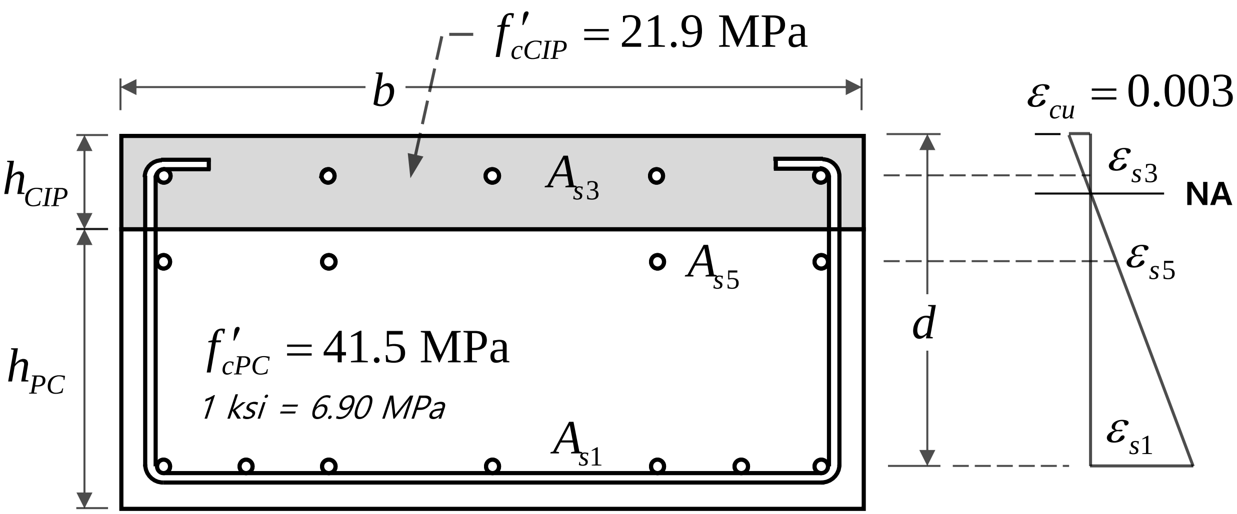


3 Nominal strengths

(1) Flexural and shear strengths of composite concrete sections

- **M_n** and **V_n** of the composite sections were calculated using the **design theory for monolithic RC members**

(a) Flexural strength:
'Composite section remains a plane'.



(a) Composite beam section **(b) Strain**

(b) Shear strength:

Nominal shear strength

$$V_n = \frac{2}{3}\rho_w^{1/3}\lambda_s\sqrt{f'_{ce}}bd + A_v f_{yv}\frac{d}{s}$$

Average concrete strength of precast and CIP concretes

$$f'_{ce} = f'_{cPC}\left(\frac{d-h_{CIP}}{d}\right) + f'_{cCIP}\left(\frac{h_{CIP}}{d}\right)$$

(1) Flexural and shear strengths of composite concrete sections

◆ Calculated strengths vs measured strengths

- **Beams #1~#3 with depth 600 mm** did not reach their capacities.
- **Beams $4~#6 with depth 450 mm:**
  (a) Test strengths P_u = 812-897 kN with shear or flexural failure
  (b) Calculated strengths P_n = 840 kN with shear failure
  } **Reasonable agreements**

Specimen	Test load		Nominal strengths (kN)		
	P_u (kN)	Failure mode	Flexural P_{nf}	Shear P_{ns}	Shear P_{nsCIP}
#1 60-w/o G	1,827	Not loaded to failure	2,350	2,440 (f_{ce}' = 36.6 MPa)	2,240 (f_{cCIP}' = 21.9 MPa)
#2 60-G10-U	1,805	Not loaded to failure	2,250		
#3 60-G07-P	1,808	Not loaded to failure			
#4 45-w/o G	812	Shear failure	840	985 (f_{ce}' = 26.2 MPa)	940 (f_{cCIP}' = 21.9 MPa)
#5 45-G08-U	887	Shear failure			
#6 45-G05-P	897	Flexural failure			

(2) Shear strengths of dapped ends

- Conventional strut-and-tie models significantly underestimates the shear strength by 50%.
- Limit analysis based on critical crack plane by Mattock and Chan

Design and Behavior of Dapped-End Beams

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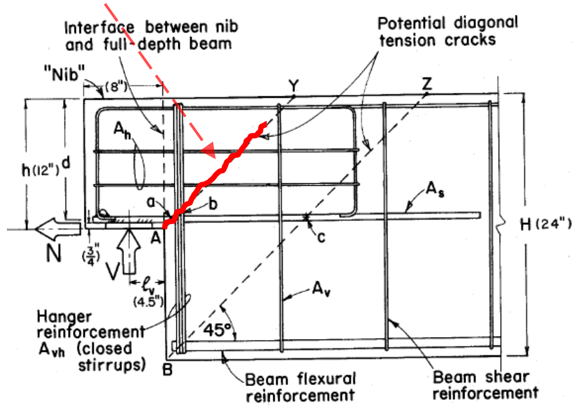
Critical crack initiating from the reentrant corner



Limit analysis along critical crack plane

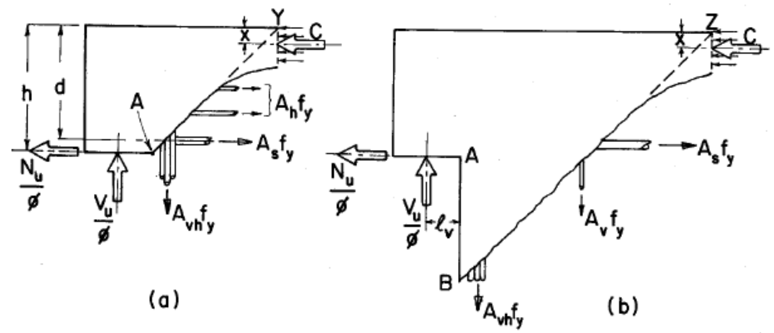
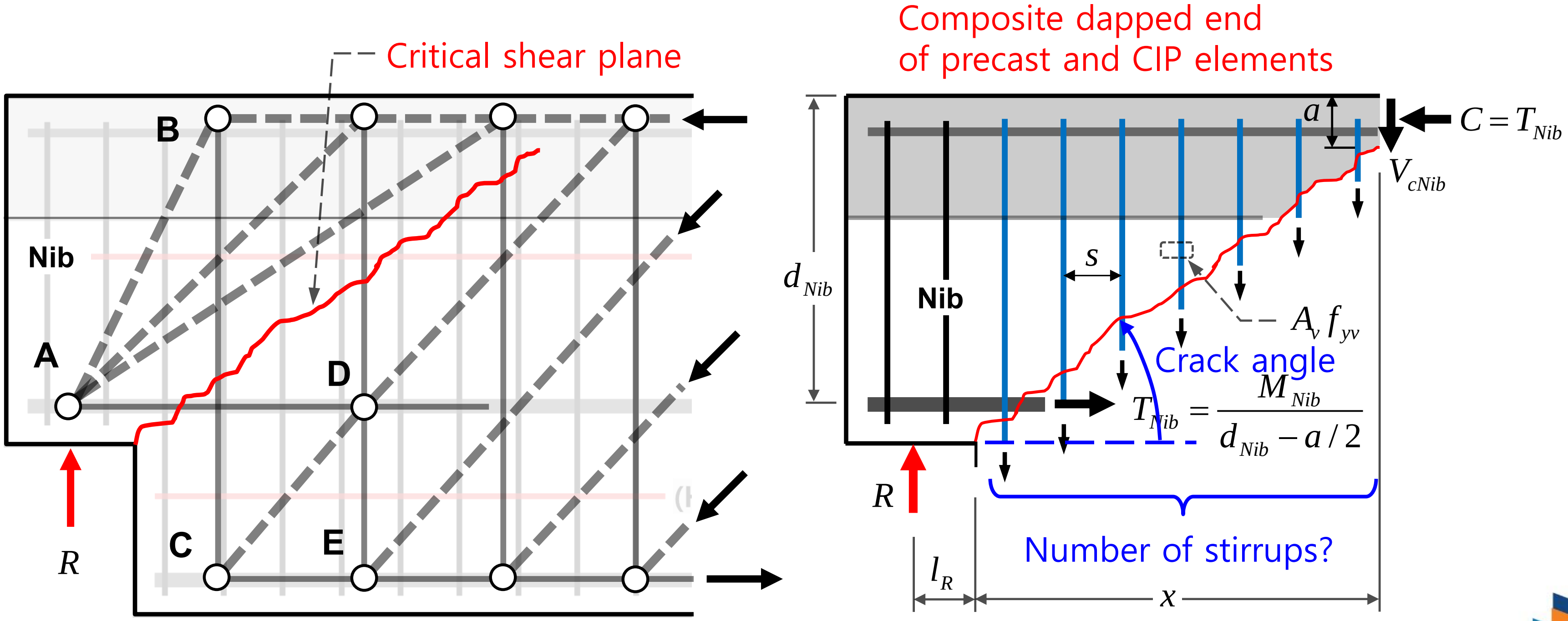


Fig. 3. Forces assumed acting on free bodies cut off by diagonal tension cracks in full-depth beam.

(2) Shear strengths of dapped ends

◆ Proposed limit analysis based on critical crack plane

- Dapped end shear strength = Strength sum of stirrups crossing the crack
- The crack angle and the number of stirrups crossing the crack need to be determined.

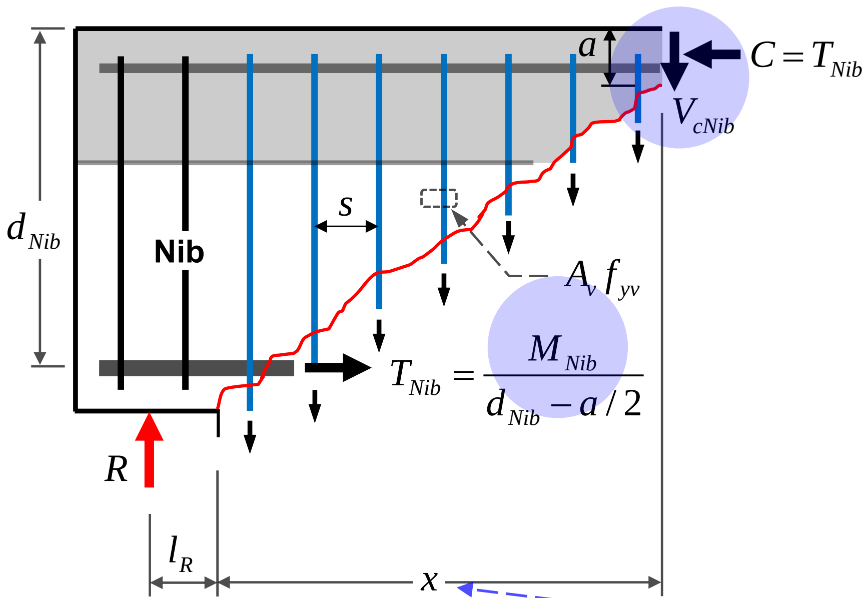


(a) Indeterminate strut-and-tie model (b) Internal forces across critical shear plane

3 Nominal strengths

(2) Shear strengths of dapped ends

- Proposed limit analysis based on critical crack plane
  - Formulation



Dapped end shear strength

$$V_{DE} = A_v f_{yv} \frac{l_R}{s} \left(\sqrt{1 + \left(\frac{V_{cNib}}{A_v f_{yv}} \frac{s}{l_R} \right)^2 + \frac{2M_{Nib}}{A_v f_{yv}} \frac{s}{l_R^2}} - 1 \right)$$

where V_{cNib} and M_{Nib} are the shear and flexural strengths of precast and CIP composite dapped section

Force equilibrium:

$$R = A_v f_{yv} \left(\frac{x}{s} \right) + V_{cNib}$$

$$R(x + l_R) = T_{Nib} \left(d_{Nib} - \frac{a}{2} \right) + A_v f_{yv} \left(\frac{x}{s} \right) \left(\frac{x}{2} \right)$$

Horizontal projection length of critical crack:

$$x = -\left(l_R + \frac{sV_{cNib}}{A_v f_{yv}} \right) + \sqrt{l_R^2 + \left(\frac{sV_{cNib}}{A_v f_{yv}} \right)^2 + \frac{2sM_{Nib}}{A_v f_{yv}}}$$

3 Nominal strengths

(2) Shear strengths of dapped ends

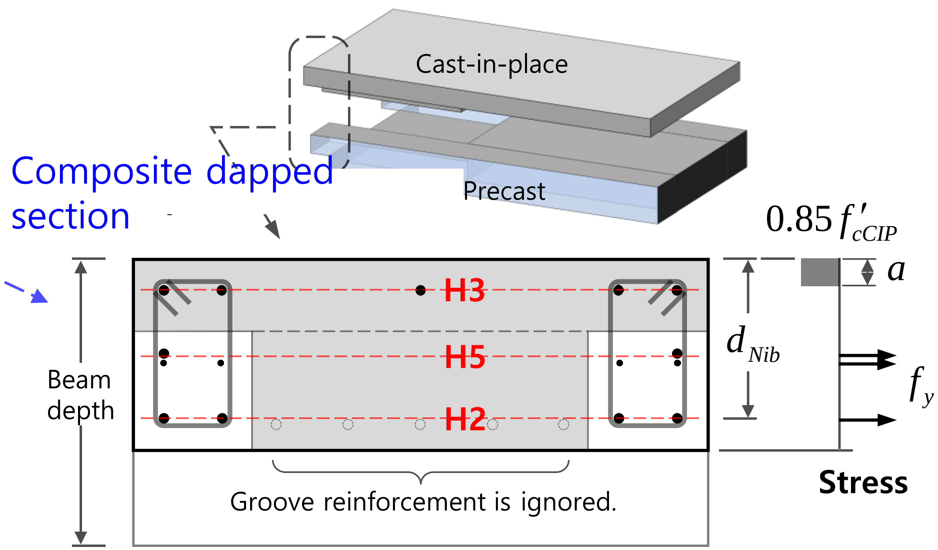
- Proposed limit analysis based on critical crack plane
  - Flexural and shear strengths of composite dapped section

Dapped end shear strength

$$V_{DE} = A_v f_{yv} \frac{l_R}{s}\left(\sqrt{1+\left(\frac{V_{cNib}}{A_v f_{yv}}\frac{s}{l_R}\right)^2 + \frac{2M_{Nib}}{A_v f_{yv}}\frac{s}{l_R^2}} - 1\right)$$

$$V_{cNIb} = \frac{2}{3}\rho_{Nib}^{1/3}\lambda_s\sqrt{f'_{cCIP}}\, b\, d_{Nib}$$

Concrete shear strength of composite dapped section ($V_{C,Nib}$)

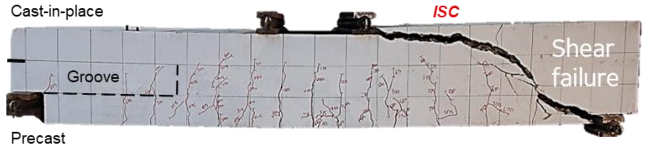


Flexural strength of composite dapped section (M_{Nib})

3 Nominal strengths

(2) Shear strengths of dapped ends

No failure at dapped ends



(e) #5 45-G08-U

- Proposed limit analysis based on critical crack plane
  - Calculated shear strengths of composite dapped ends

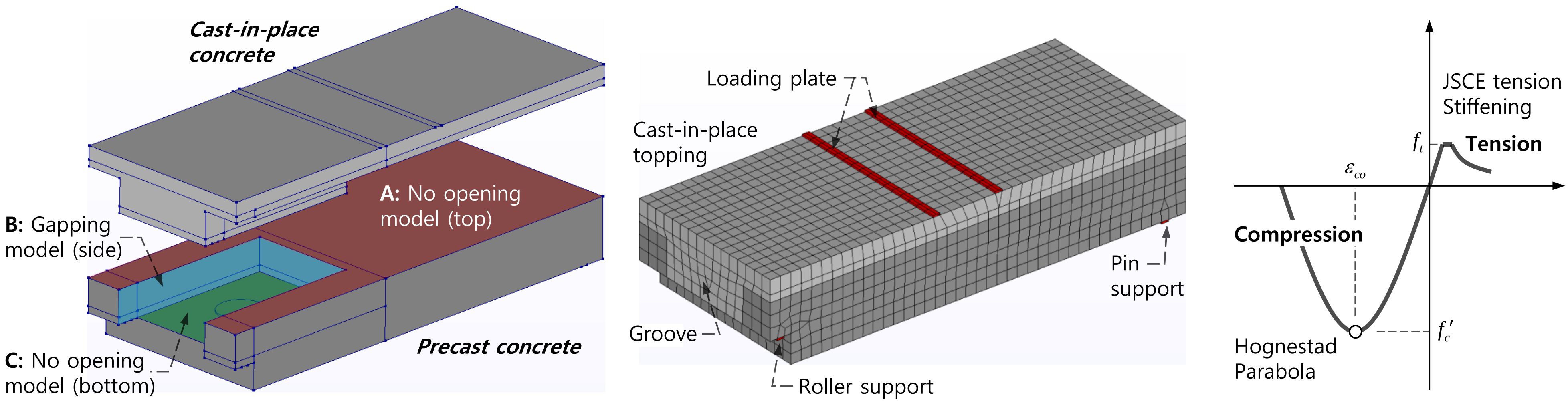
Specimen	M_{Nib} 1) (kN-m)	A_v (mm^2)	f_{yv} (MPa)	s (mm)	V_{cNib} 3) (kN)	x 4) (mm)	V_{DE} 4) (kN)	P_{DE} (kN)
#1 60-w/o G	1,935	508	531	100	289	423	1,540	3,000
#2 60-G10-U	1,548	508	531	100	260	373	1,310	2,550
#3 60-G07-P	1,548	508	531	100	260	373	1,310	2,550
#4 45-w/o G	990	284	566	113 2)	174	452	718	1,400
#5 45-G08-U	792	284	566	113 2)	152	351	595	1,160
#6 45-G05-P	792	284	566	113 2)	152	351	595	1,160

1) M_{Nib} = nominal flexural strength of the nib section (see Fig. 15 (c)).
2) For specimens #4 to #6, the spacing of vertical stirrups was defined as (75+150)/2 mm (see Fig. 4 (b1)).
3) $\rho_{Nib} = [T_{Nib}/f_y]/[bd_{Nib}]$ and $\lambda_s = \sqrt{(2/[1+d_{Nib}/254])}$ (≤ 1.0, d_{Nib} in mm), where $T_{Nib} = M_{Nib}/[d_{Nib}-0.5a]$; d_{Nib} = 360 mm for #1 to #3 and 260 mm for #4 to #6; $a = T_{Nib}/[0.85 f_{cCIP}' b]$; and f_y = yield strength of the reinforcement H2 (see Fig. 15 (b)).
4) l_R = 75 mm.

4 Numerical investigations

(1) Finite Element Modeling

- DIANA FEA 10.5 Total strain crack model based on Modified Compression Field Theory for RC
- Concrete interface modeling between precast and CIP: Coulomb friction model
  - **Smooth interface B with separation:** Gapping model
  - **Rough interfaces A and C without separation:** No opening model

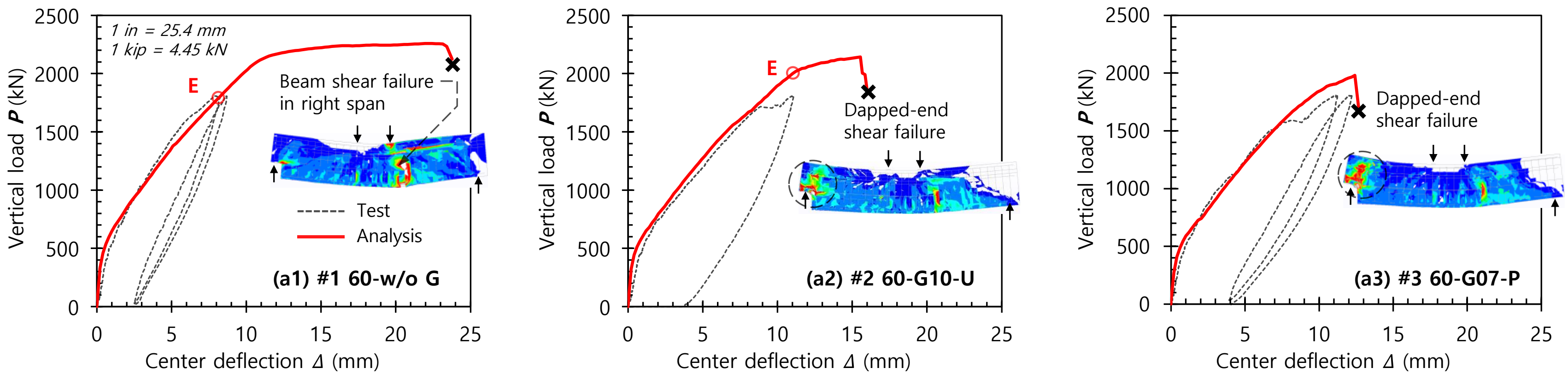


(a) Concrete blocks and interfaces **(b) Mesh discretization** **(c) Concrete behavior**

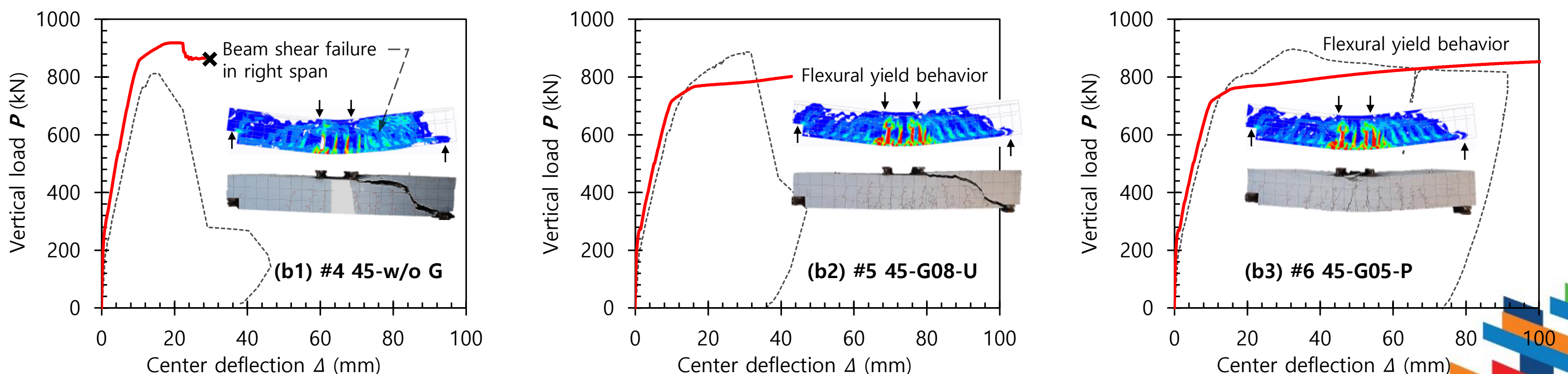
4 Numerical investigations

(2) Analysis results

◆ Test vs Analysis



(a) Composite beam specimens with full depth of 600 mm

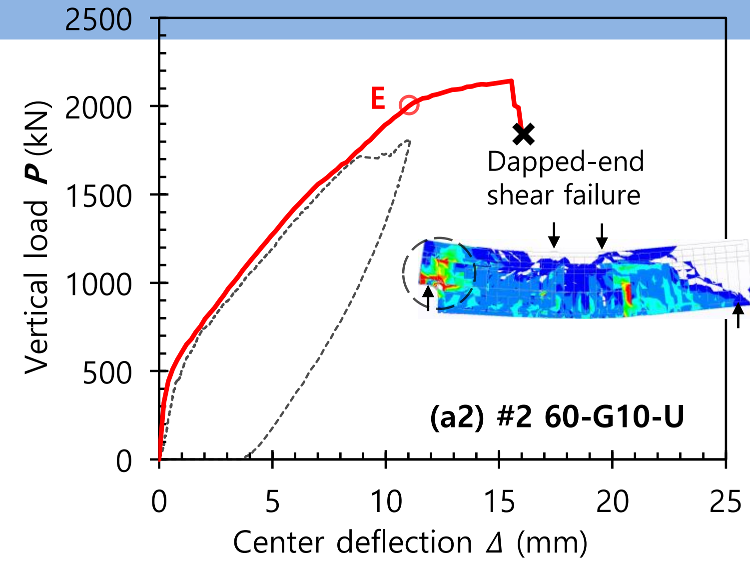


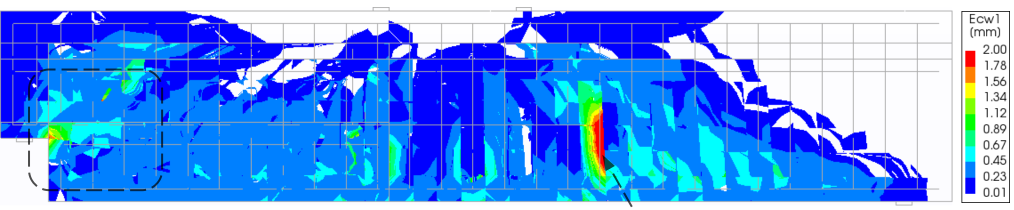
(b) Composite beam specimens with full depth of 450 mm

4 Numerical investigations

(2) Analysis results

- Concrete and reinforcement stresses
  - Conventional beam behavior:
    (a) flexural yielding at midspan
    (b) flexure-shear damage in right span
  - Dapped end (left span):
    (a) strut action, (b) stirrup stresses

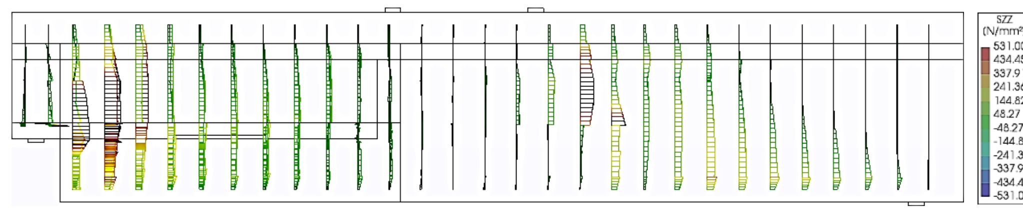




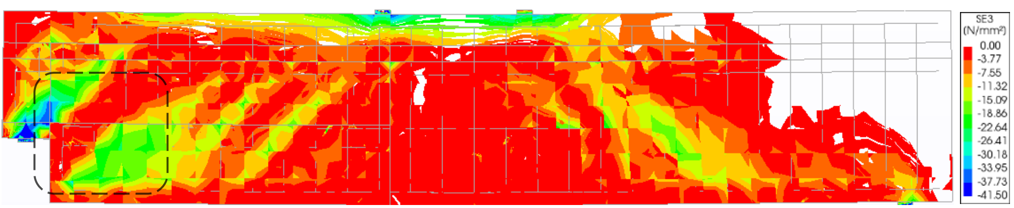
Concrete damage and strut action at dapped end with groove detail

(b1) Crack width

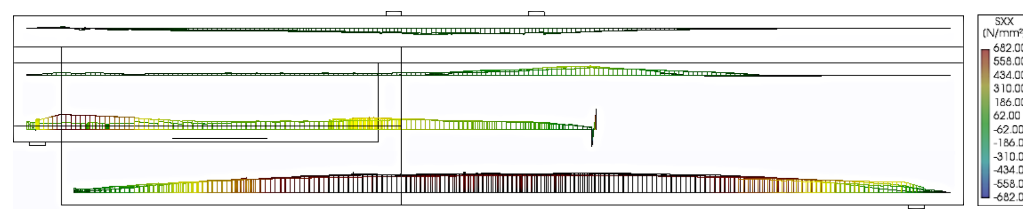
Bar cut-off (H2)



(b3) Vertical reinforcement stress



(b2) Concrete principal stress (in compression)



(b4) Horizonal reinforcement stress

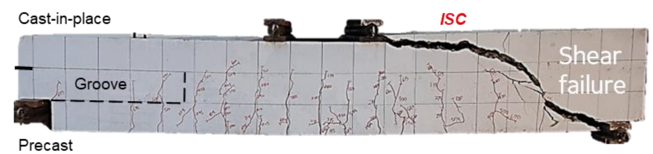
(b) Specimen #2 60-G10-U (beam depth 600 mm and with groove)

4 Numerical investigations

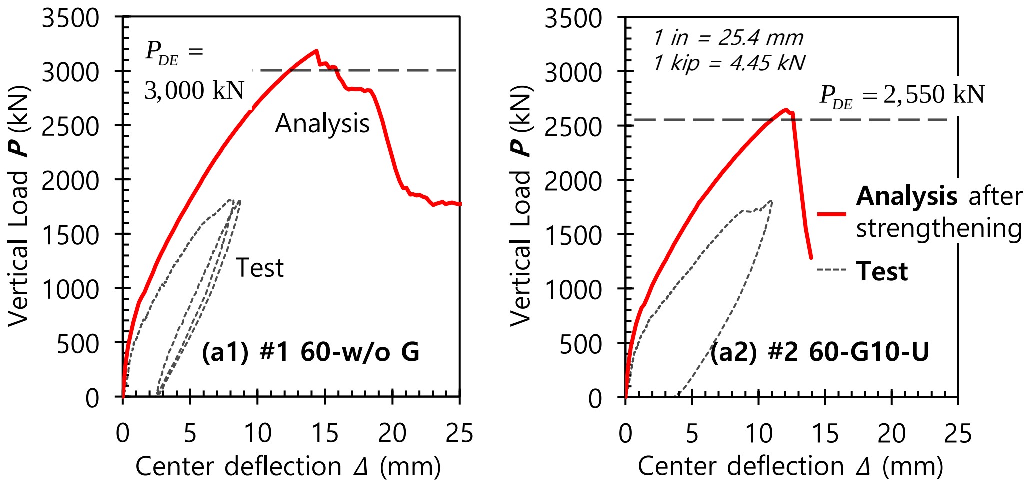
(3) Shear strength of composite dapped ends

- Reanalysis leading to dapped end shear failure
  - Reinforcement area increase other than dapped ends
- Comparison of dapped end shear strengths: prediction vs Analysis

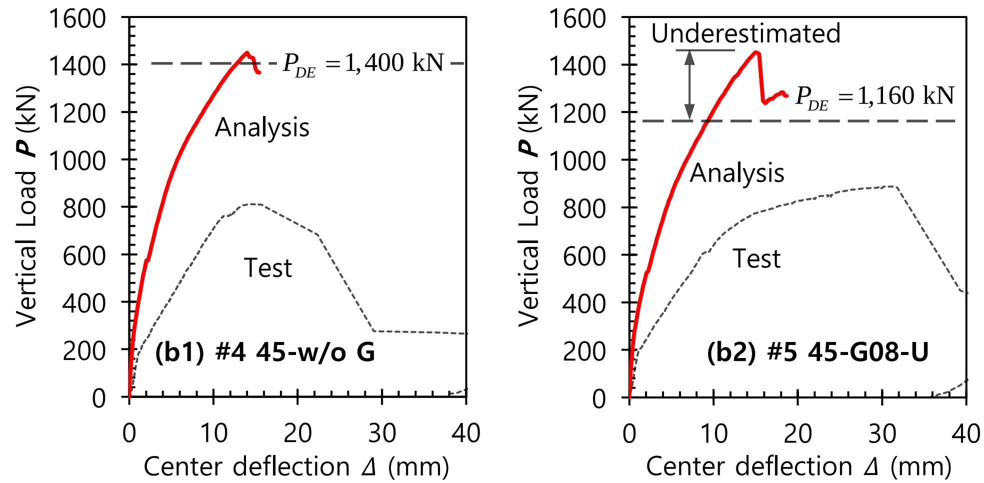
No failure at dapped ends in test



(e) #5 45-G08-U



(a) Specimen #1 and #2 with beam height = 600 mm

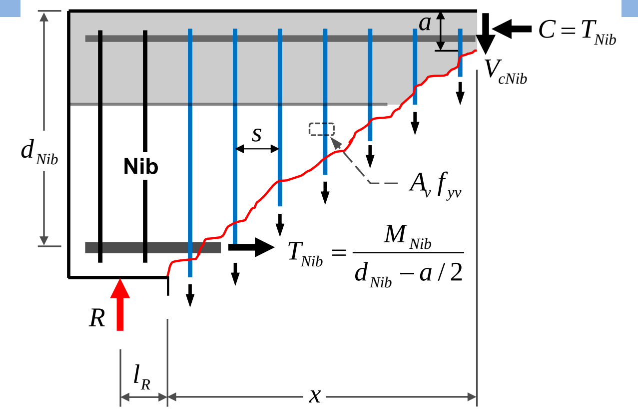


(b) Specimen #4 and #5 with beam height = 450 mm

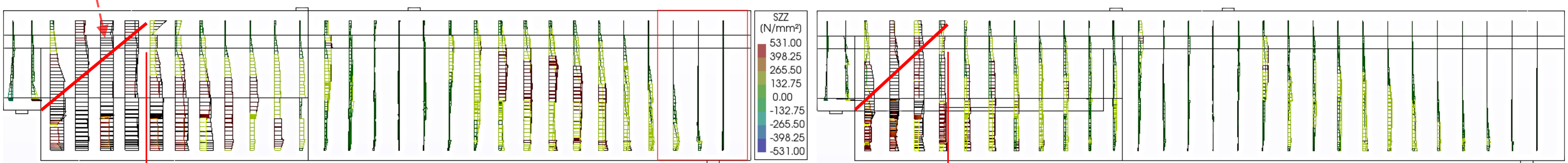
4 Numerical investigations

(3) Shear strength of composite dapped ends

- Crack angle and stirrup stresses



Calculated critical crack plane



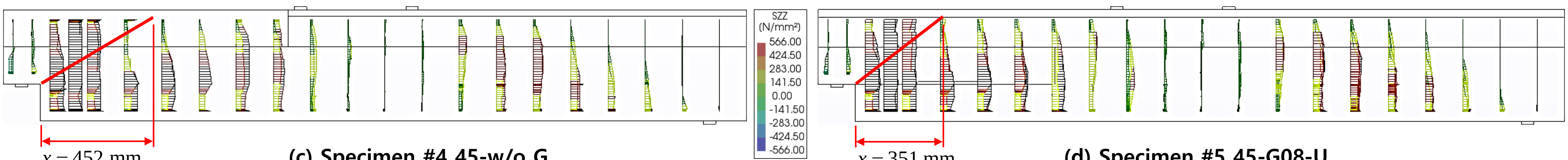
$x = 423$ mm

(a) Specimen #1 60-w/o G
(beam depth 600 mm and no groove)

1 in = 25.4 mm
1 kip = 4.45 kN
1 ksi = 6.90 MPa

$x = 373$ mm

(b) Specimen #2 60-G10-U
(beam depth 600 mm and with groove)



$x = 452$ mm

(c) Specimen #4 45-w/o G
(beam depth 450 mm and no groove)

$x = 351$ mm

(d) Specimen #5 45-G08-U
(beam depth 450 mm and with groove)

Thank you for your attention.