ACI CONCRETE CONVENTION

Advancements in Anchoring to Concrete Construction

Commemorating the lifetime contributions of Prof. Dr. Ing. Rolf Eligehausen

"Concrete break-out failure of hooked and headed bars in RC column joins"

A study in the field of **Civil Engineering, Fastening and Connections**

Angelo MARCHISELLA, **Giovanni MUCIACCIA**

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Overview

1. Introduction
2. Methods
3. Experimental References
4. Levels of Approximation
5. Results and Discussion
6. Conclusions

About development length

Development Length in RC Beam-Column Joints

- Addressed for hook and headed steel bars
- Empirically expressed in ACI-318

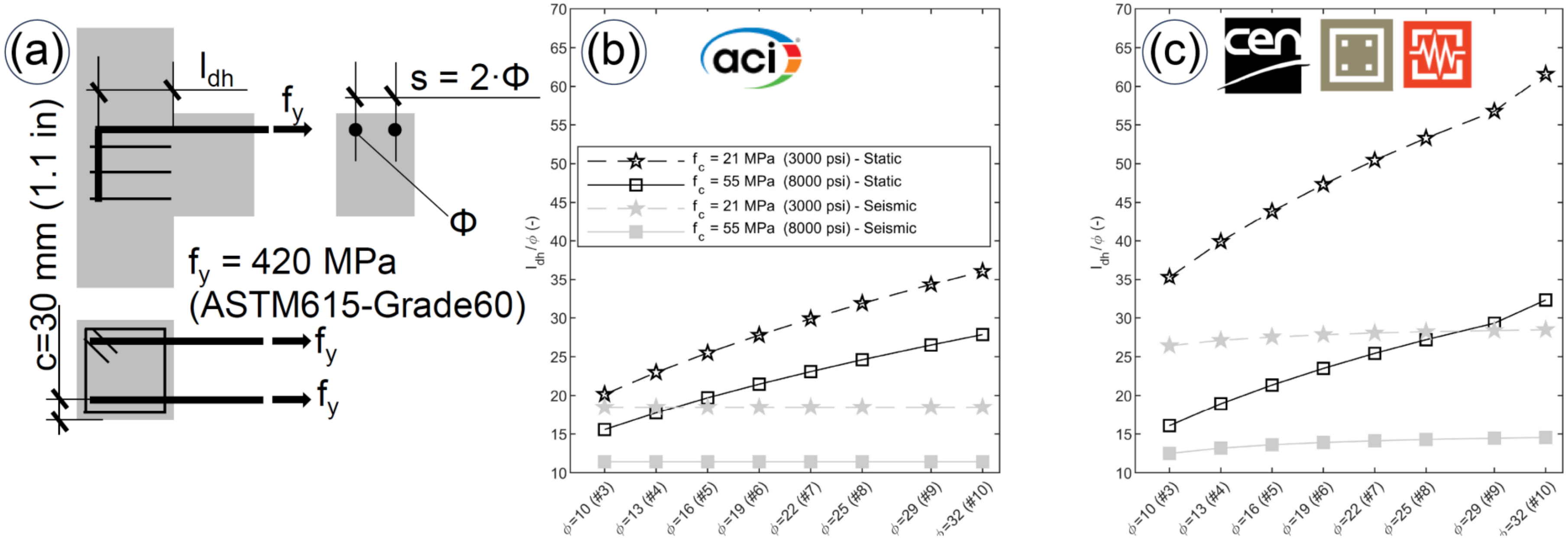
Factors Affecting Development Length

- Yield strength of reinforcement
- Compressive strength of concrete
- Bar diameter
- Boundary conditions like light-weighted concrete, epoxy coating, confining reinforcement

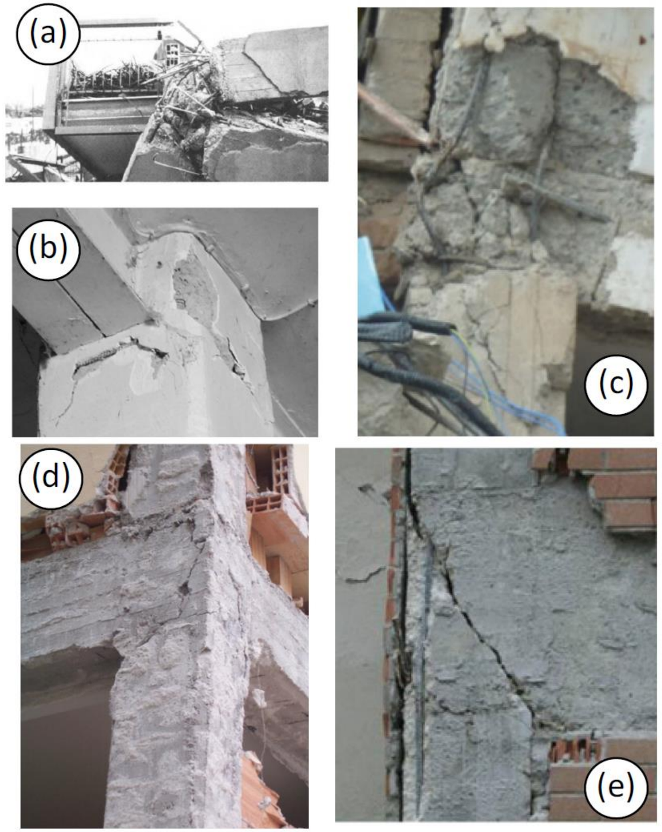
Failure Mechanisms Identified

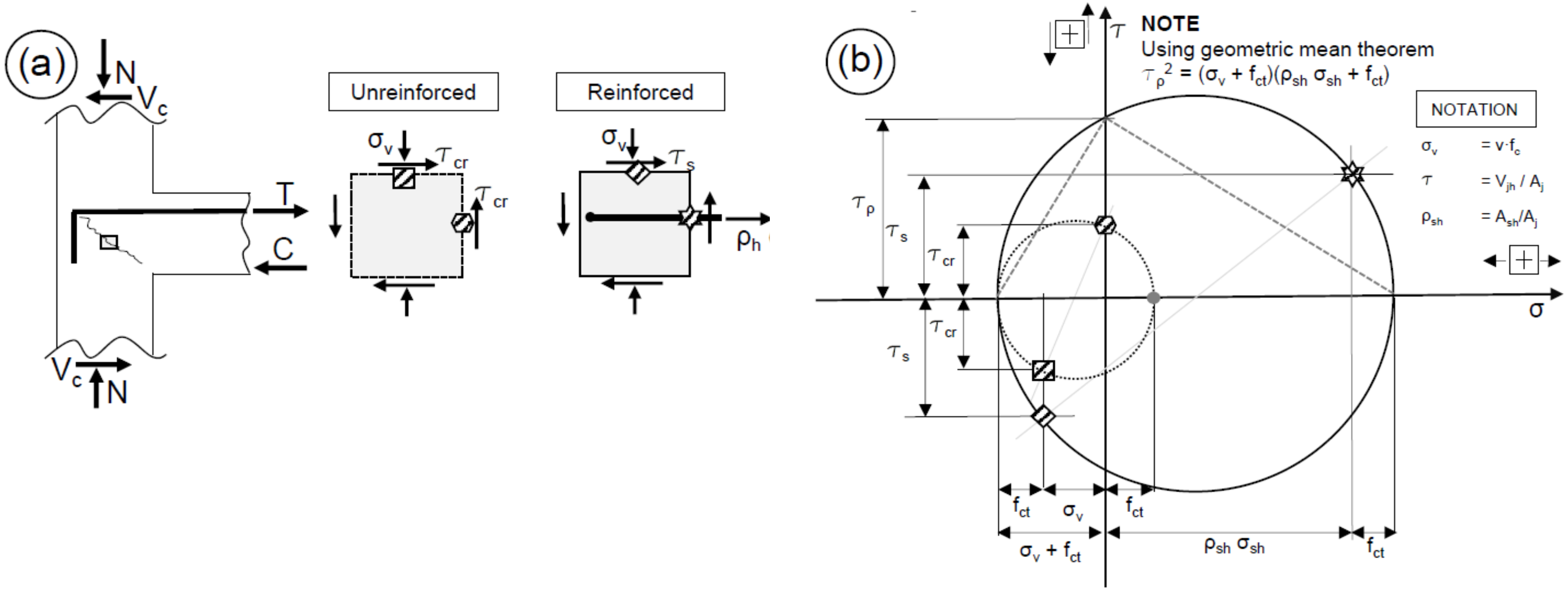
- Concrete-break out failure (CB)
- Joint-shear failure (JS)

Assessment of Mechanical Behavior


(a)
l_{dh}
f_y
s = 2·Φ
Φ
c=30 mm (1.1 in)
f_y = 420 MPa
(ASTM615-Grade60)
(b)
aci
f_c = 21 MPa (3000 psi) - Static
f_c = 55 MPa (8000 psi) - Static
f_c = 21 MPa (3000 psi) - Seismic
f_c = 55 MPa (8000 psi) - Seismic
l_{dh}/ϕ (-)
ϕ=10 (#3)
ϕ=13 (#4)
ϕ=16 (#5)
ϕ=19 (#6)
ϕ=22 (#7)
ϕ=25 (#8)
ϕ=29 (#9)
ϕ=32 (#10)
(c)

About shear strength of beam-column joints

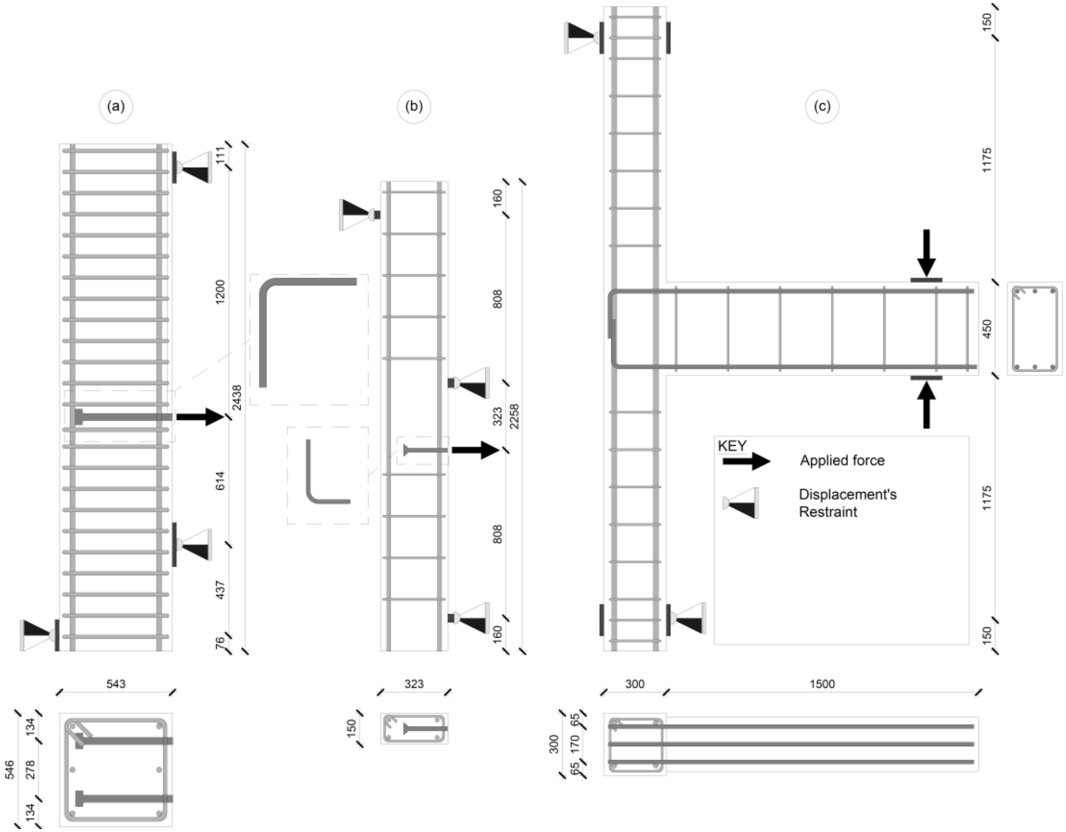




(a) Irpinia 1980 ; (b) Molise 2002; (c) Emilia 2012; L'Aquila 2009 (d) and (e)

10.1016/j.prostr.2023.01.073

How testing was carried out?



(a)-(b) column-type adapted from Shao et al. (2016), Chun and Kim (2004); (c) sub-assemblage adapted from Kuang and Wong (2006)

Historical Context

- First application by Jirsa and Marques (1975)
- Further studies by Pinc et al. (1977)
- Peckover and Darwin (2013)
- Kim et al. (2023)

Three failure mechanisms observed

- Concrete-break out failure (CB)
- Joint-shear failure (JS)
- Pullout/splitting failure (PO)

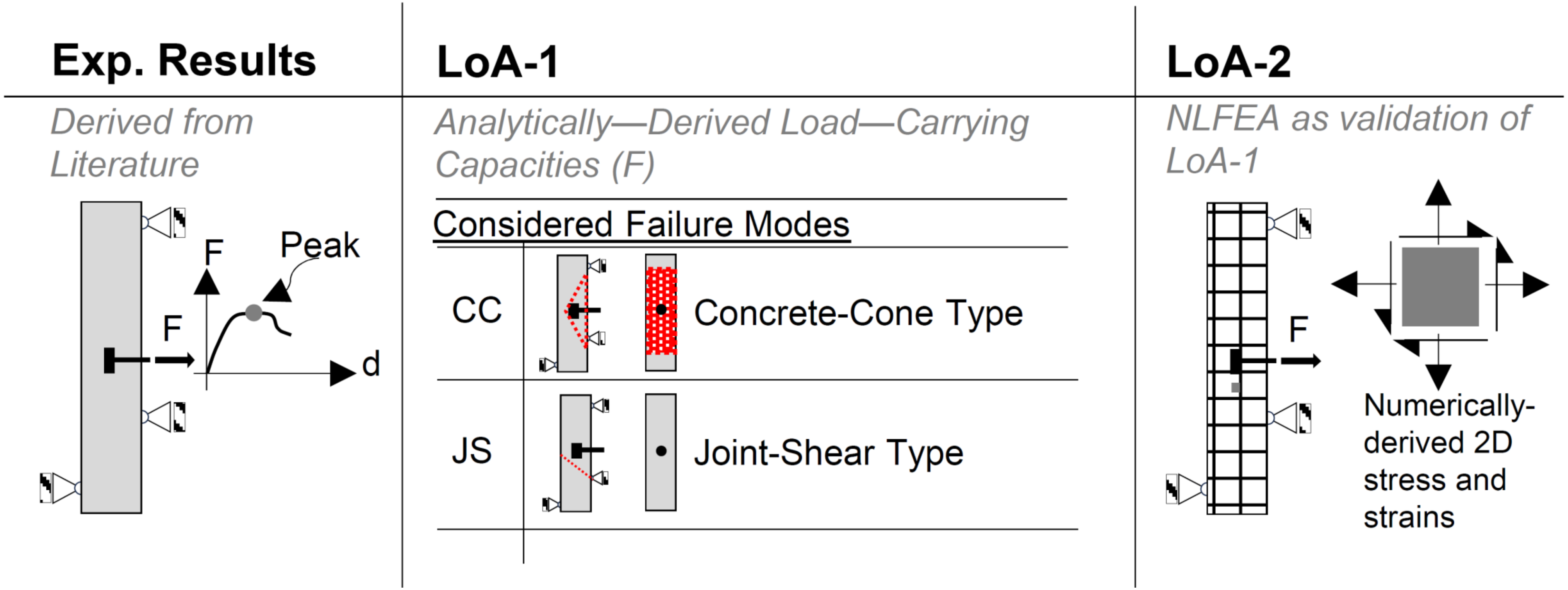
Questions rising

Which is the difference between Concrete Breakout and Joint Shear failure?

Which are the implications for node design?

Are we in the context of concrete-cone mechanism ?

Proposed methodology



Levels-of-Approximation (LoA) Methodology, Inspired by Muttoni and Ruiz (2012) and adopted in fib Model Code (2013)

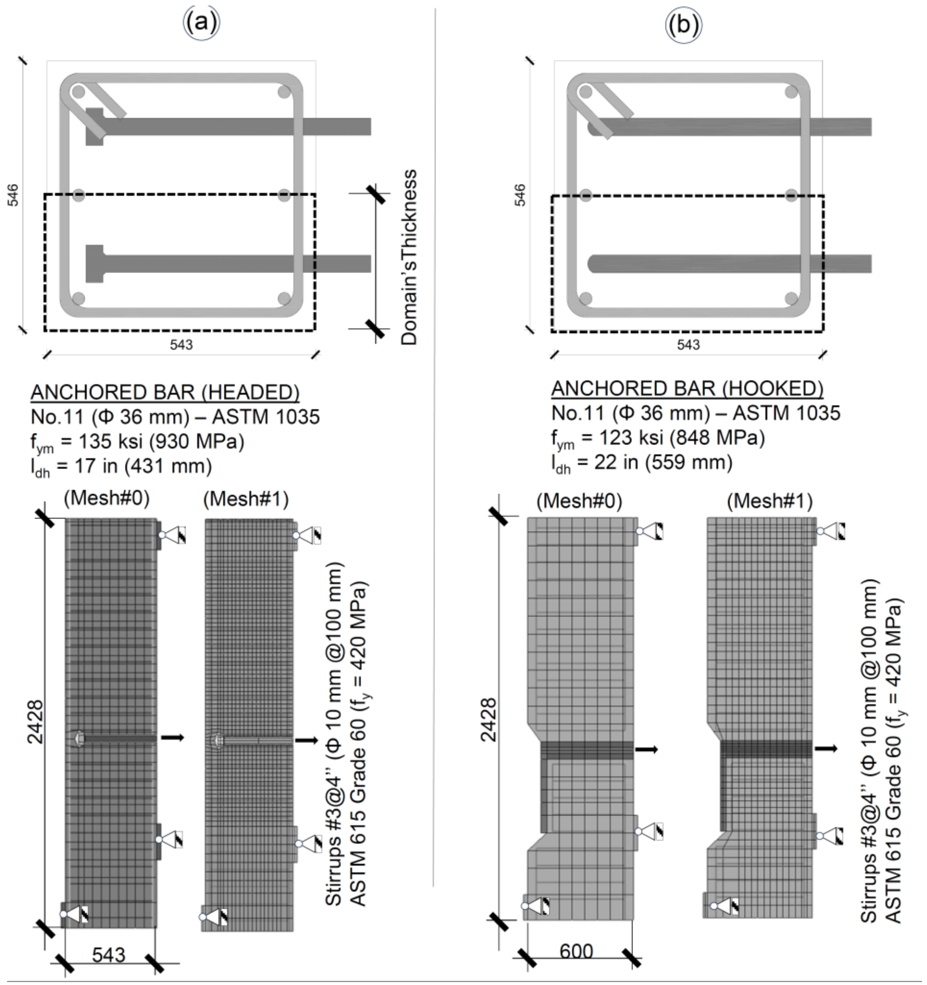
Focus of current investigation

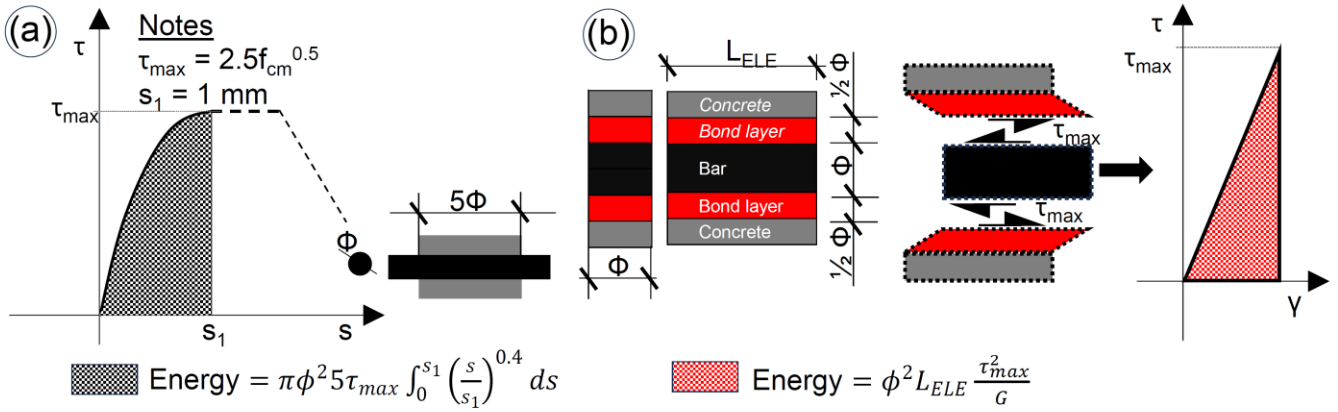
Selection of Beam-Column Joint Tests
- Tests from Sperry et al. (2015) and Shao et al. (2016)
- Focus on CB mode failures

Specimen Details
- Large diameter bars (#11; 36 mm)
- High strength steel (ASTM 1035 – Grade 120, f_{yk} = 820 MPa)
- Embedment depth: 17 in (431 mm)

Confining Reinforcement
- Hoops No. 3 (10 mm), with ≅ 0.3% reinforcement ratio
- ASTM 615 - Grade 60 (f_{yk} = 420 MPa)

Column-type specimens by Shao et al. (headed) and by Sperry et al (hooked)

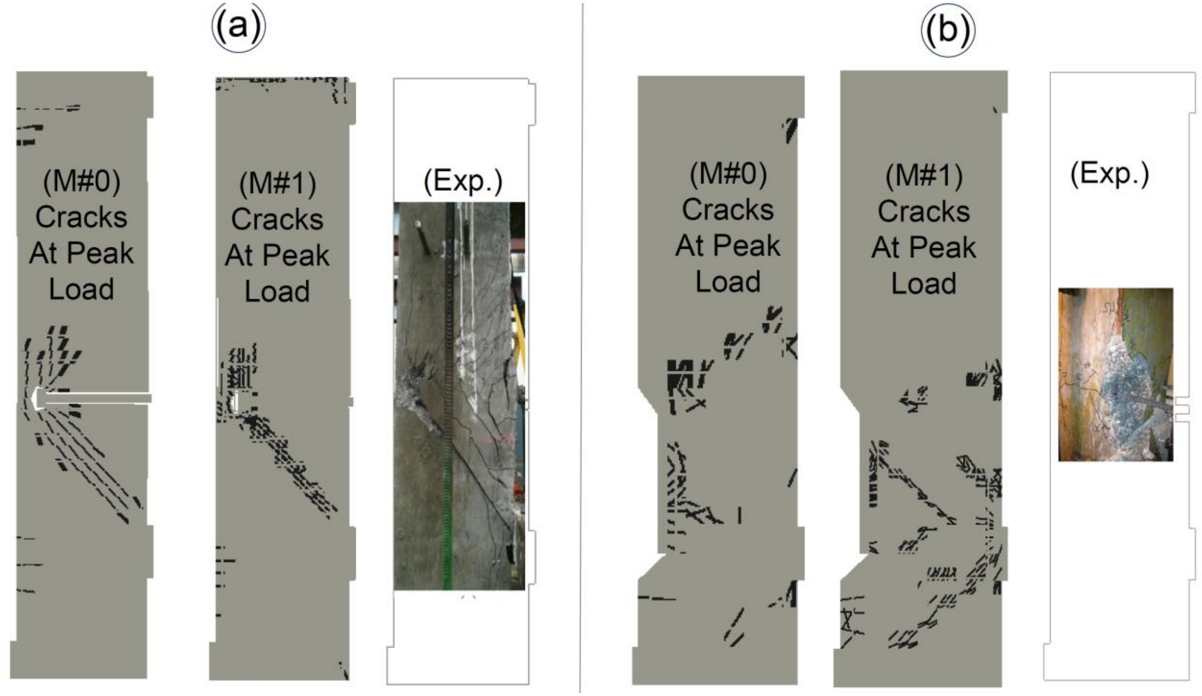


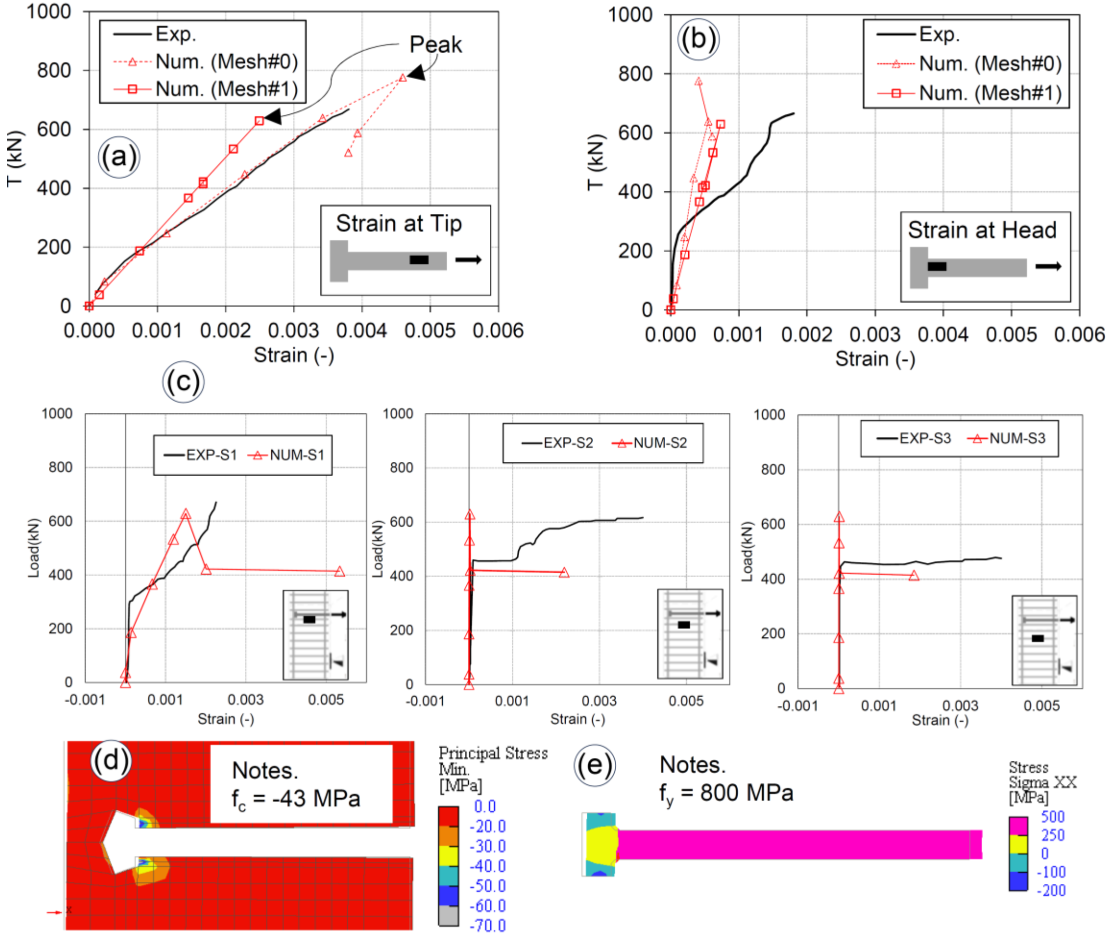


Bond-slip behavior at the interface between the bar and the surrounding concrete was modeled using a fictitious elastic layer with thickness almost equal to half diameter of the bar.

Elastic parameters of the layer such as tangential modulus (G) was calibrated such that a segment of the layer associated with one element (LELE) had elastic energy equivalent to the one derived by applying local bond-to-slip law according to fib (2013) for a bond length equal to five times the bar's diameter

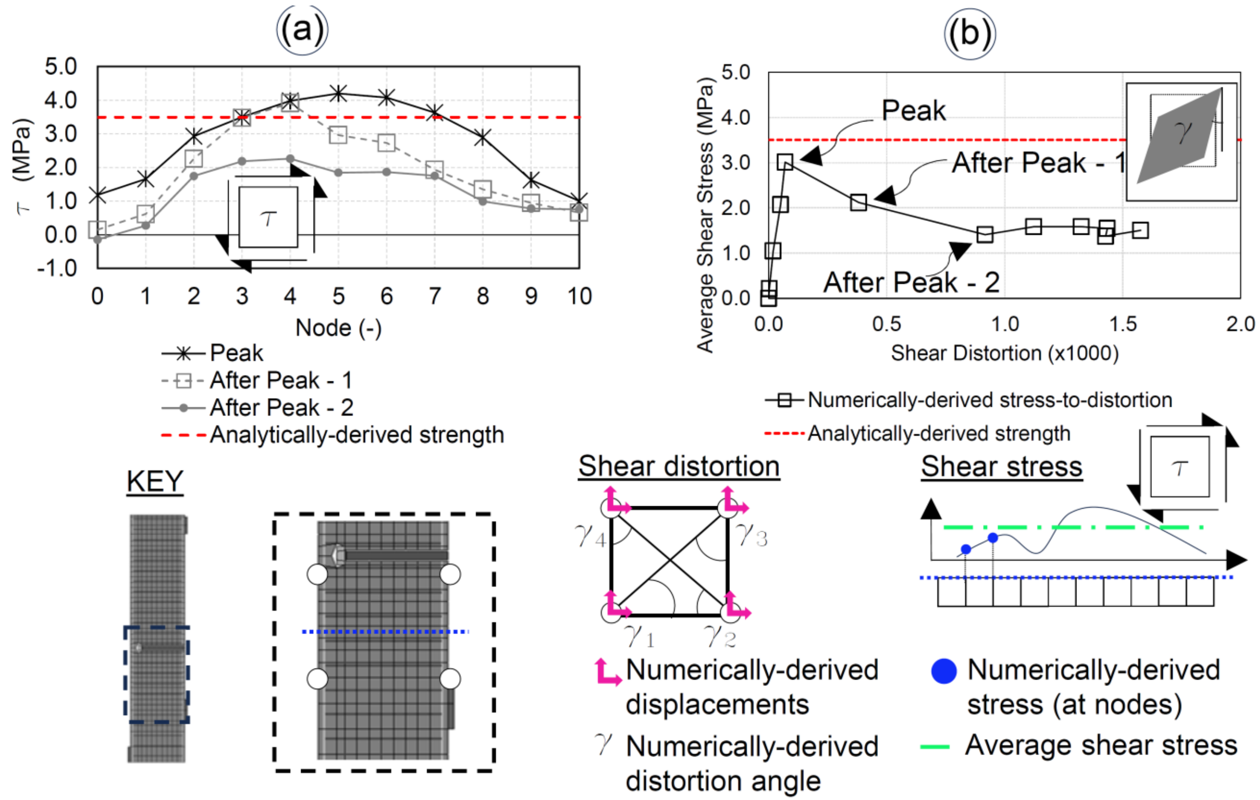
Main results /1

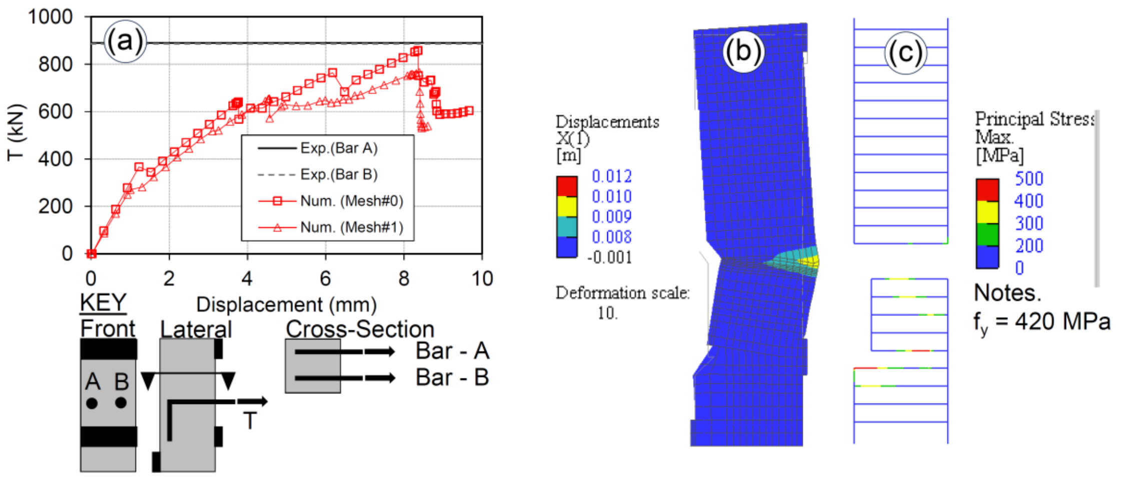




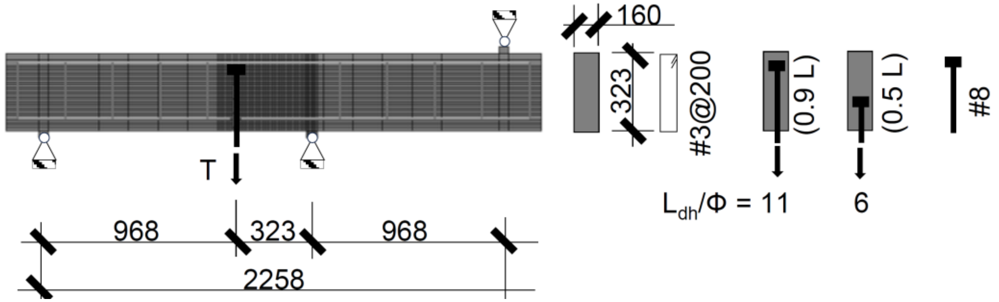
		Exp.	LoA-1			LoA-2
TEST	Type	T_{exp}	T_j	T_{dh}	T_{cc}	T_{LoA-2}
		(kN)	(kN)	(kN)	(kN)	(kN)
11-5-f3.8-6#3-i-2.5-3-17		685	527	555	154	629
11-12-90-6#3-i-2.5-2-22		885	812	812	264	857

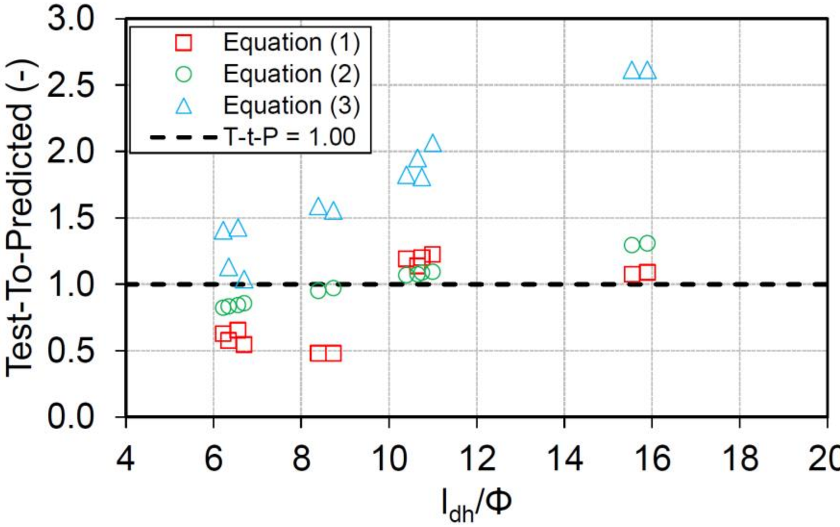
Main results /2

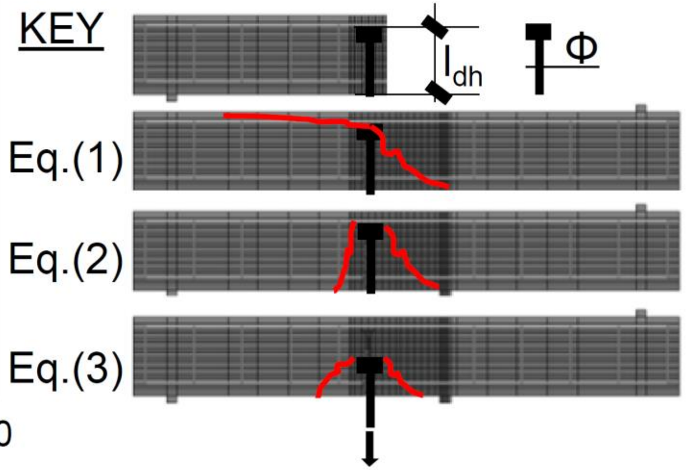




Column-type specimen by Chun et al. (2009)



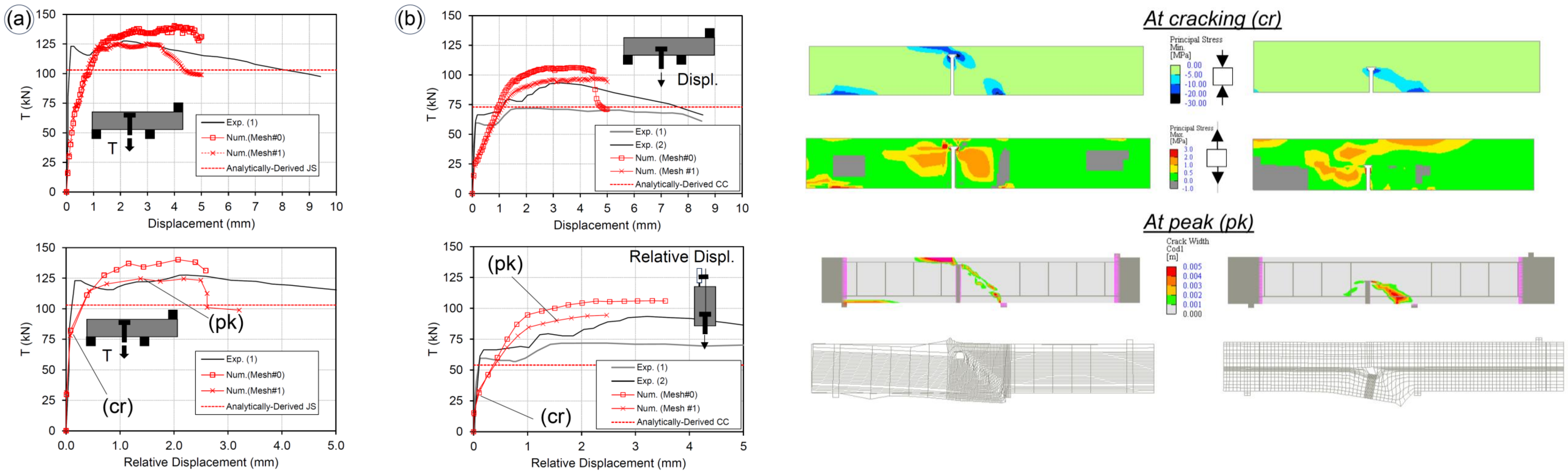




$$T_j = A_j \tau_j \text{ with } \tau_j = f_{ct} \cdot \sqrt{1 + \frac{\nu f_c}{f_{ct}}}$$

$$T_{dh} = C\, f_c^{\alpha}\, l_{dh}^{\beta}\, d_b^{\epsilon}$$

$$T_{cc} = k_c \frac{A_N}{A_{N0}} \cdot l_{dh}^{1.5} \sqrt{f_c}$$


(a)
T (kN)
Displacement (mm)
Exp. (1)
Num.(Mesh#0)
Num.(Mesh#1)
Analytically-Derived JS
T
(b)
Displ.
Exp. (1)
Exp. (2)
Num. (Mesh#0)
Num. (Mesh #1)
Analytically-Derived CC
Relative Displacement (mm)
(pk)
(cr)
Relative Displ.
At cracking (cr)
Principal Stress Min. [MPa]
Principal Stress Max. [MPa]
At peak (pk)
Crack Width Cod1 [m]

Conclusions

1. **Concrete Break-Out Failure**: The analyses revealed that there is a need of identifying failure modes in testing. This distinction is crucial for accurate assessment and design of beam-column joints

2. **Levels-of-Approximation (LoA)**: Two levels of approximation were used in the numerical analyses:
    - **LoA-1**: This level focused on predicting the maximum tensile force and identifying failure mechanisms such as shear failure, ‘anchorage failure’ and concrete-cone failure
    - **LoA-2**: This level utilized advanced non-linear finite element models to provide a detailed analysis of the mechanical behavior of the joints

3. **Comparison of Crack Patterns**: The numerical analyses compared the crack patterns derived from the models with those observed in experimental tests. The major diagonal crack formation indicated shear behavior, and additional diagonal cracks were observed in the experimental tests

4. **Concrete Break-Out vs. Joint Shear Failure**: The analyses showed that concrete-cone type failure may be not representative of the actual failure mechanism in some cases. The comparison of analytically-derived and experimental tensile forces highlighted the differences in failure modes.

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…some thoughts

FASTENING ELEMENTS IN CONCRETE STRUCTURES

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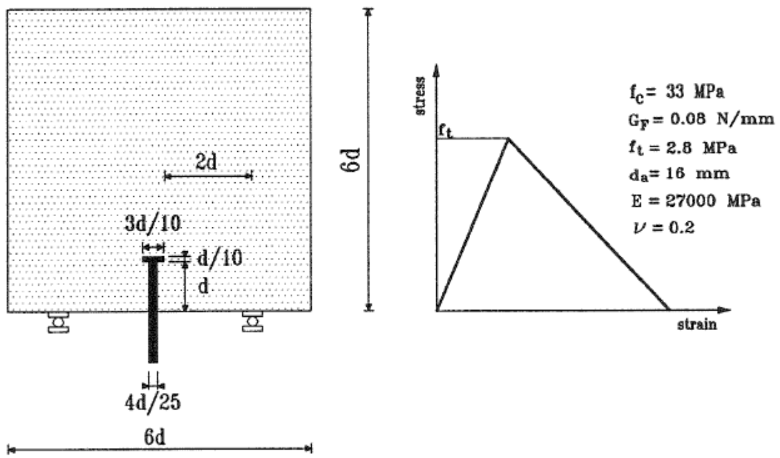

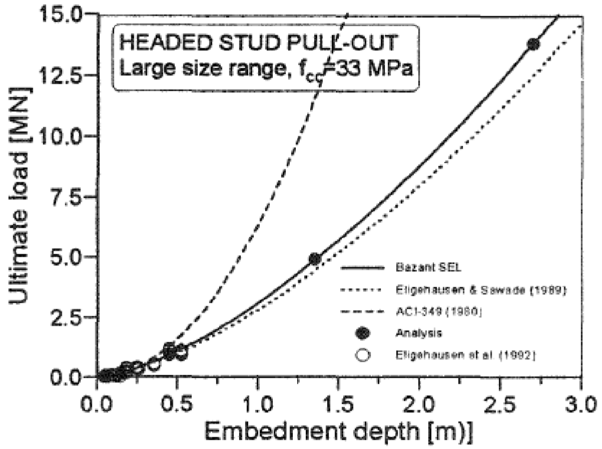

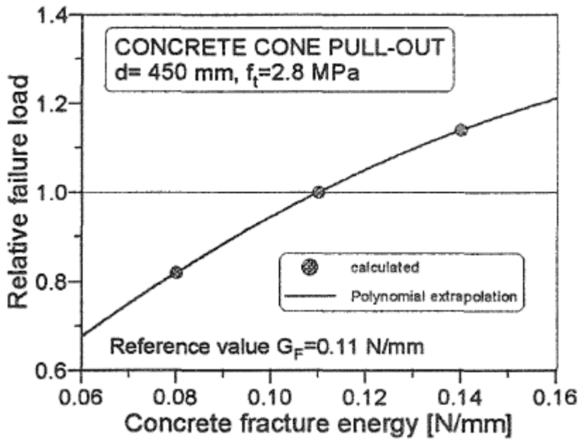

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Thanks for your attention

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