

Effects of Early-Age Material Properties on Concrete Slab Deflections

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Today's Agenda

- Stress-Strain Curve at Young Ages
- Moment Curvature Analysis
- Next Steps
- Conclusions

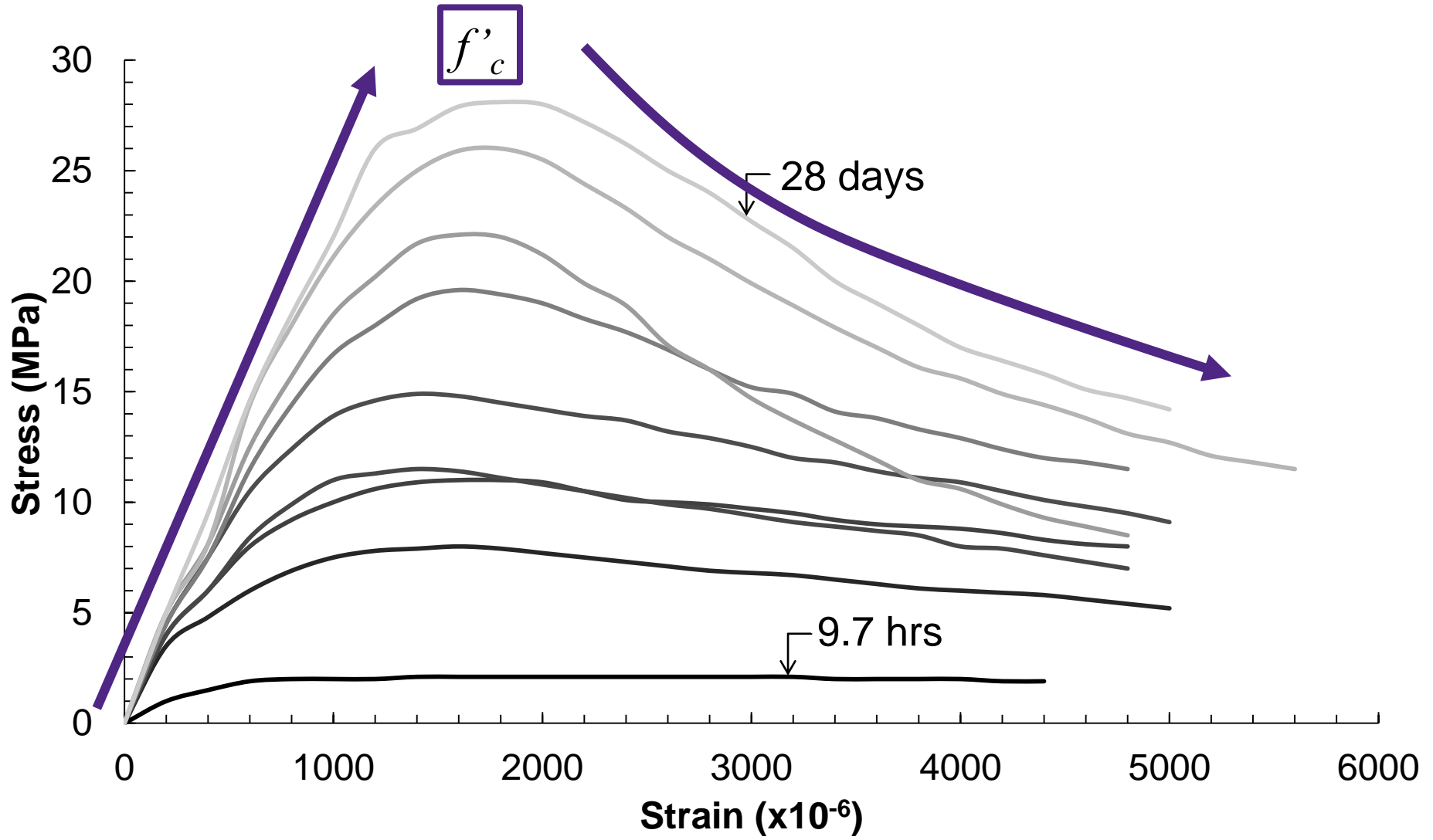
Importance for Deflections

- Young-age loading due to:
 - Chosen formwork method, and;
 - General construction schedule
- High loads on young concrete causes cracking
- Do conventional models still apply to very young concrete?

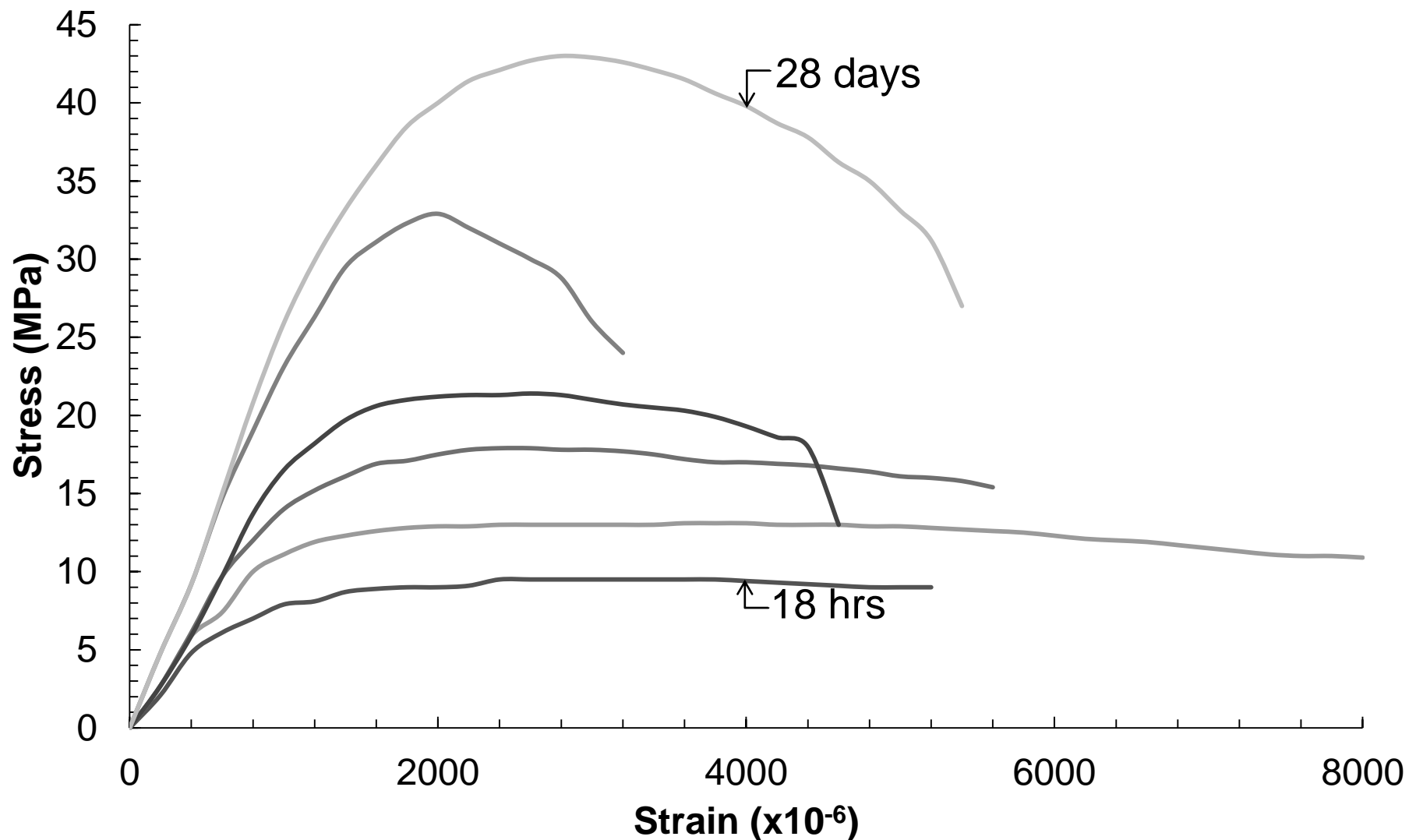
$$E_c = 57,000\sqrt{f'_c} \quad I_{cr} = \frac{b(kd)^3}{3} + nA_s(d - kd)^2$$

Stress-Strain Curves for Early-Age Concrete

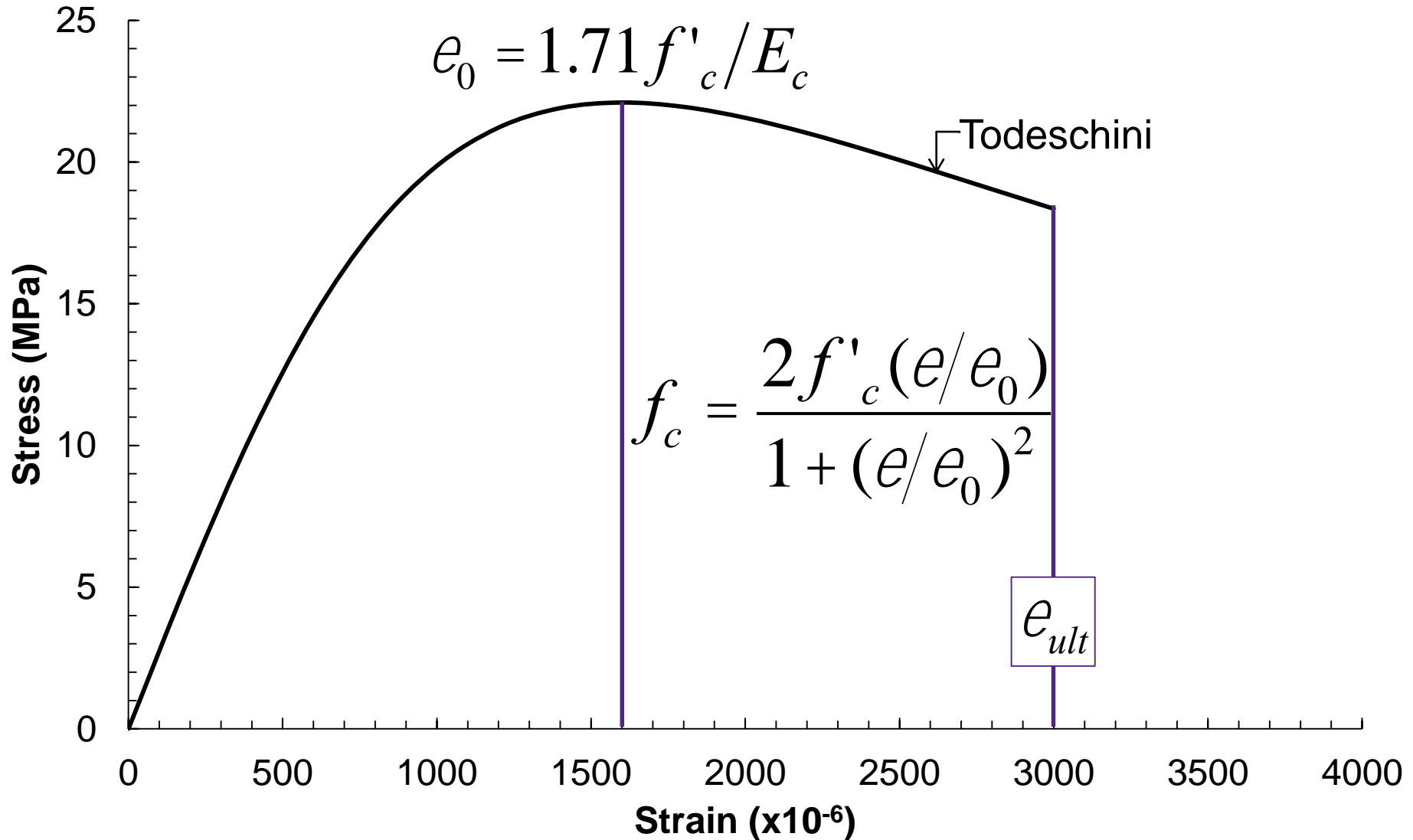
Khan, Cook & Mitchell (1995)



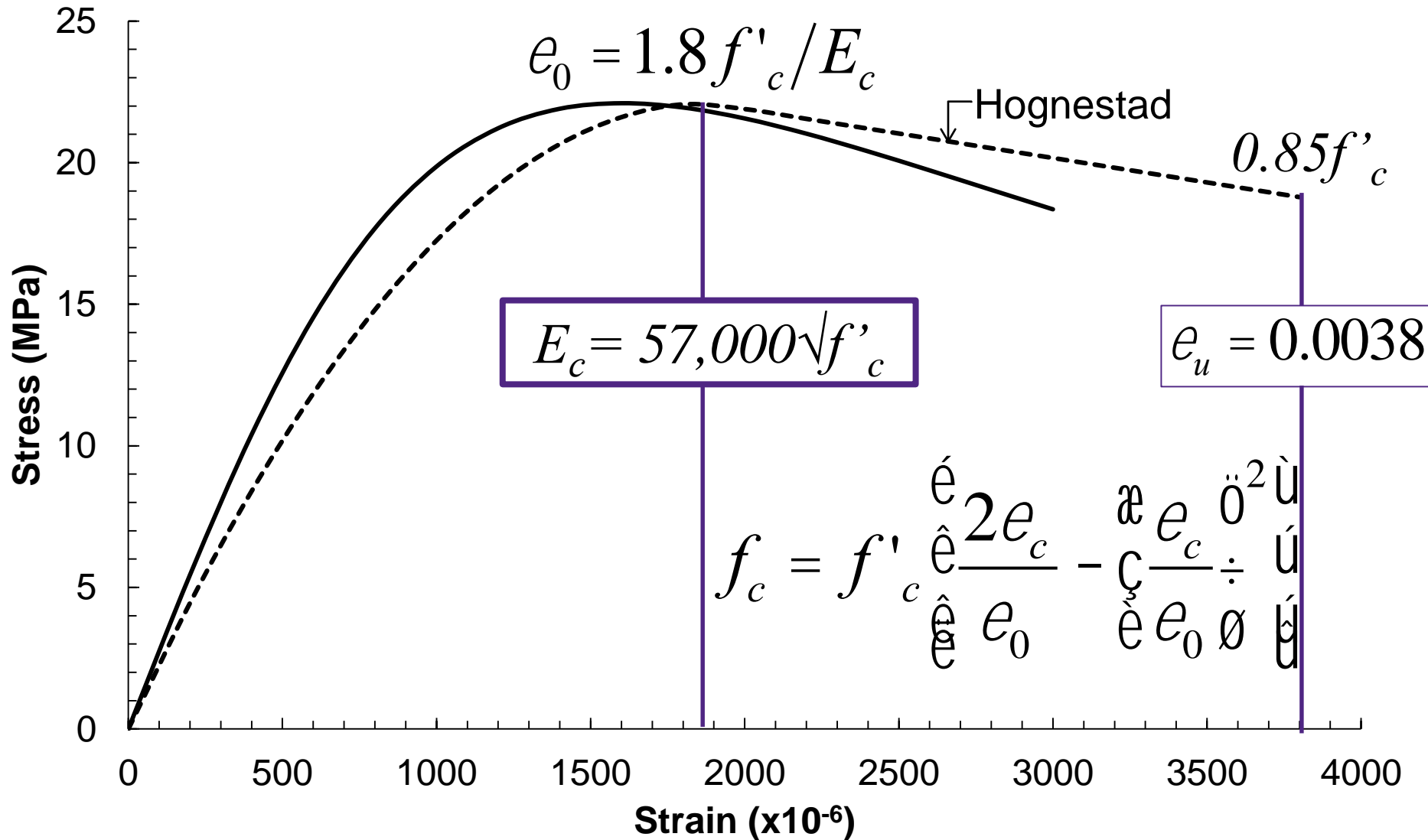
Jin, Shen & Li (2005)



Equations for σ_c - ε_c Diagrams



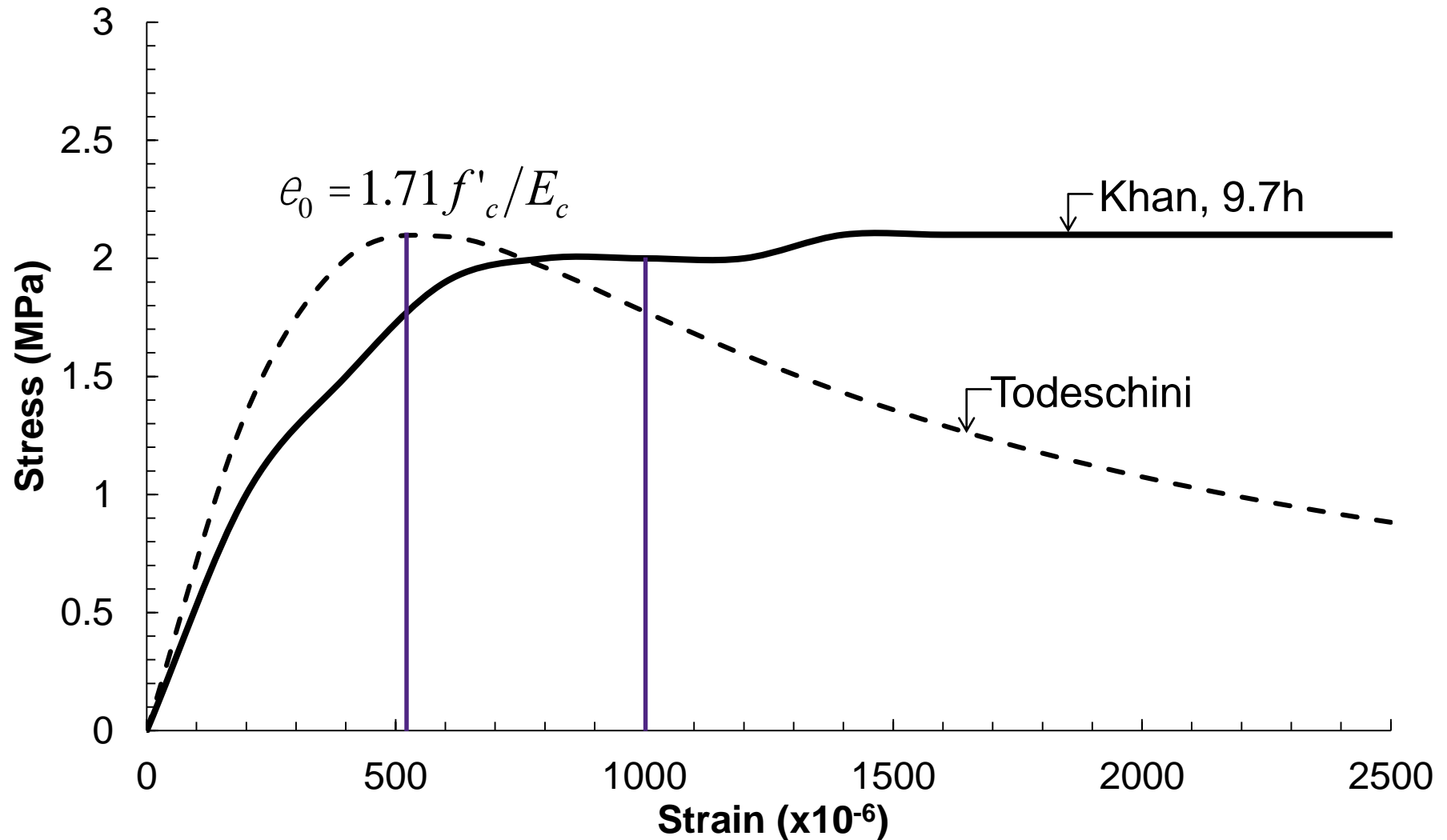
Equations for σ_c - ϵ_c Diagrams



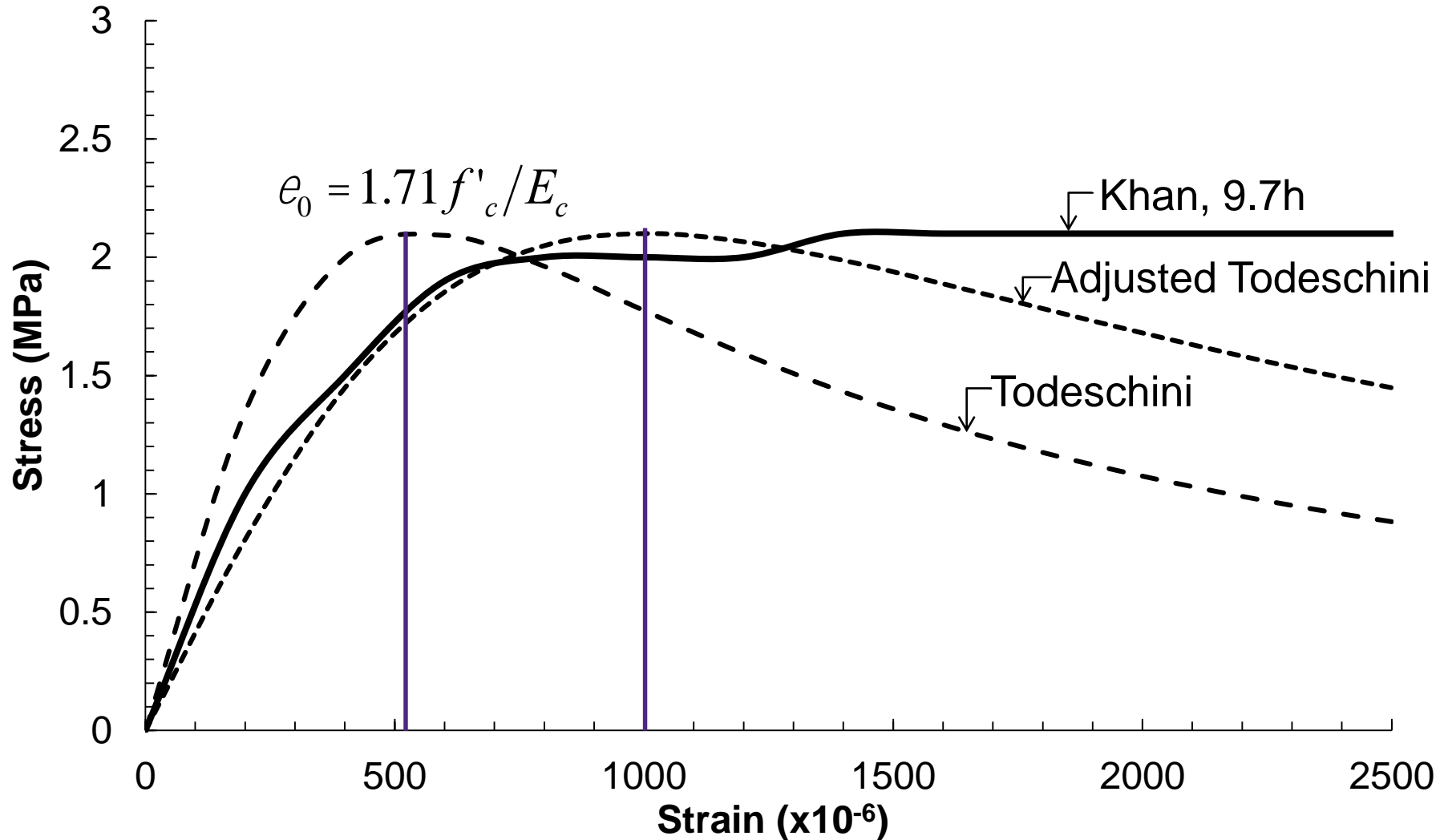
Initial Findings

- Conventional relationships predict strain-softening behaviour
- Equations underestimate ε_0 for young concrete
- Adjusting ε_0 will fit data but underestimates ascending branch

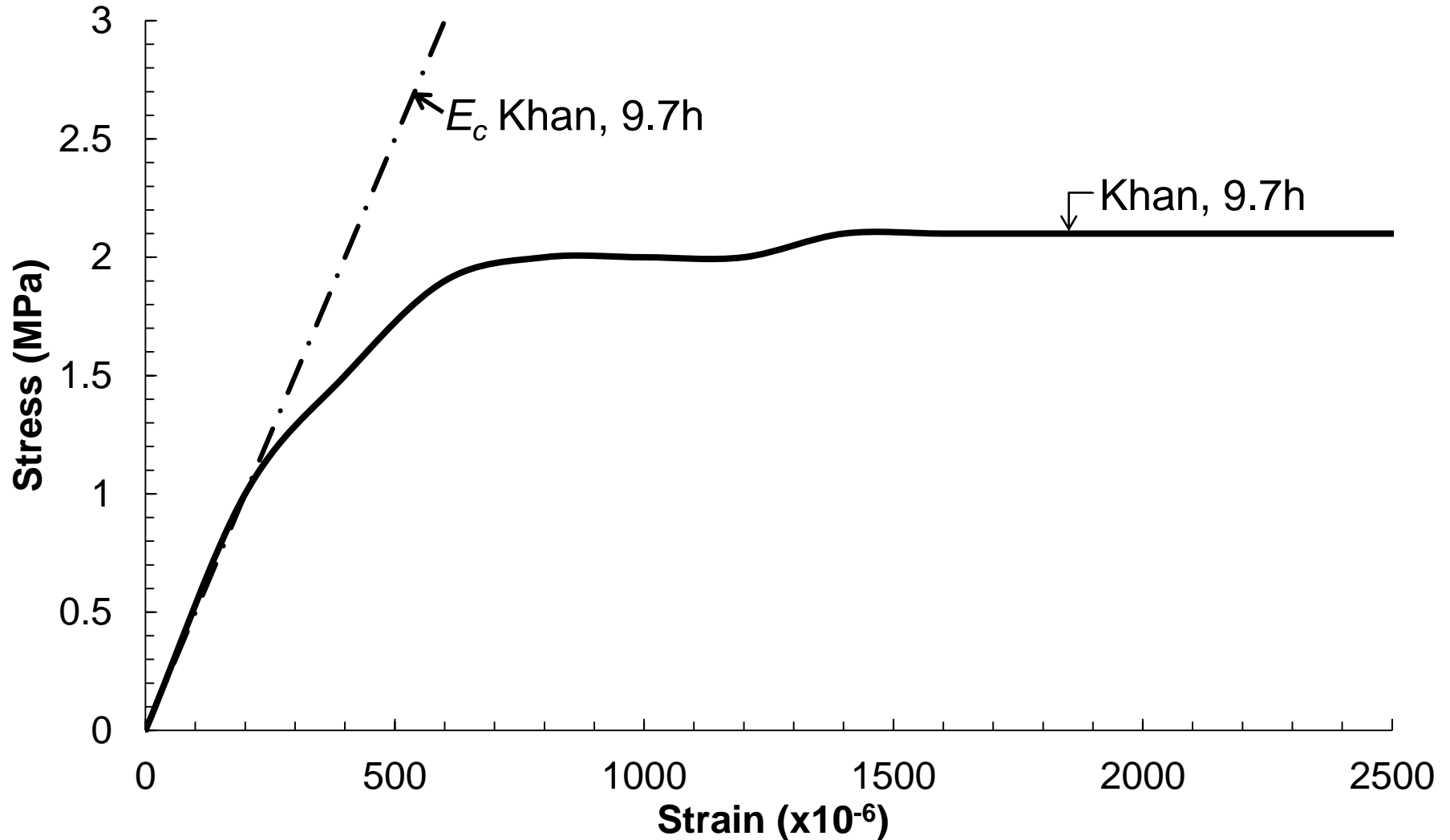
Todeschini at Early Ages



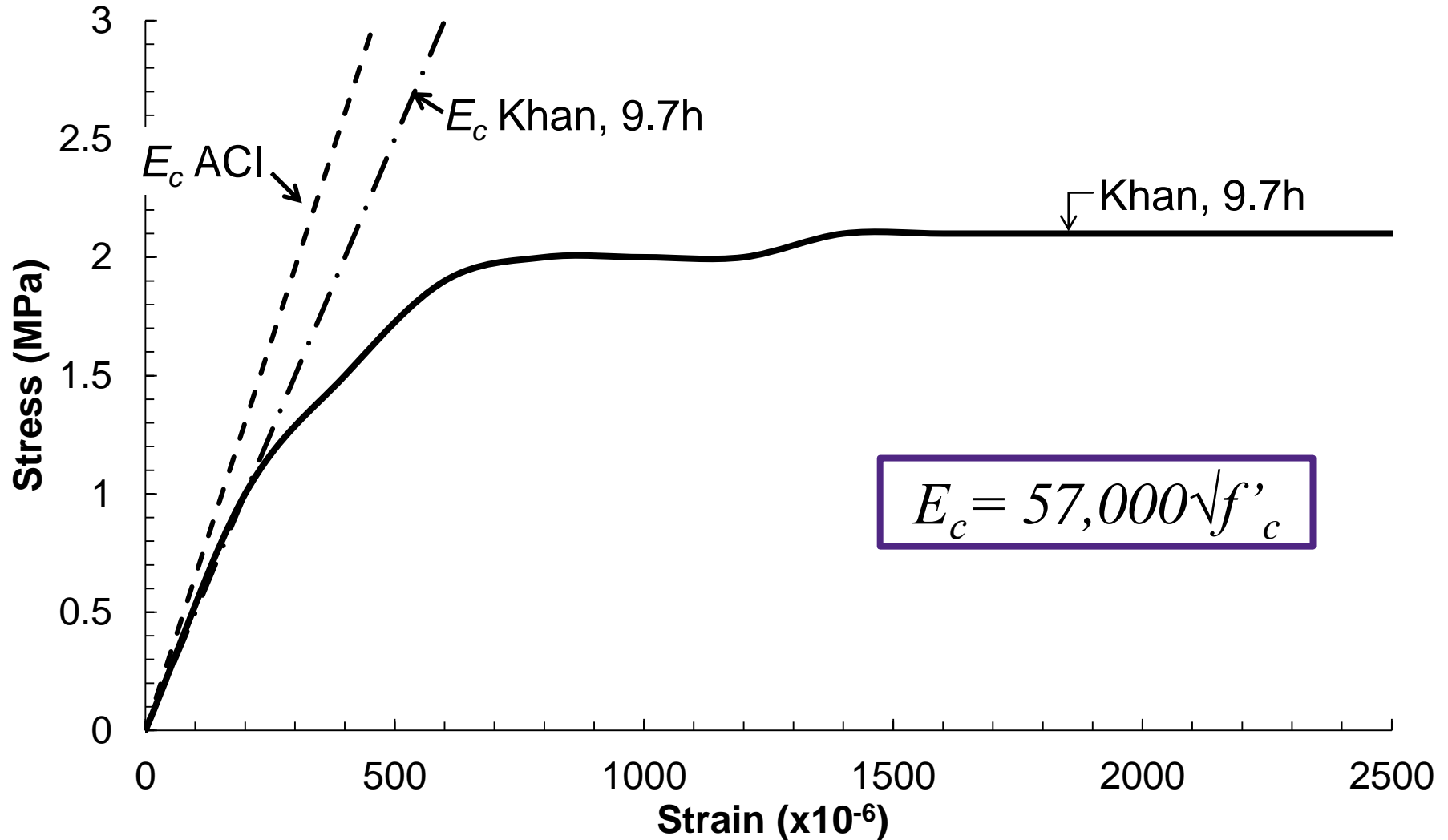
Todeschini at Early Ages



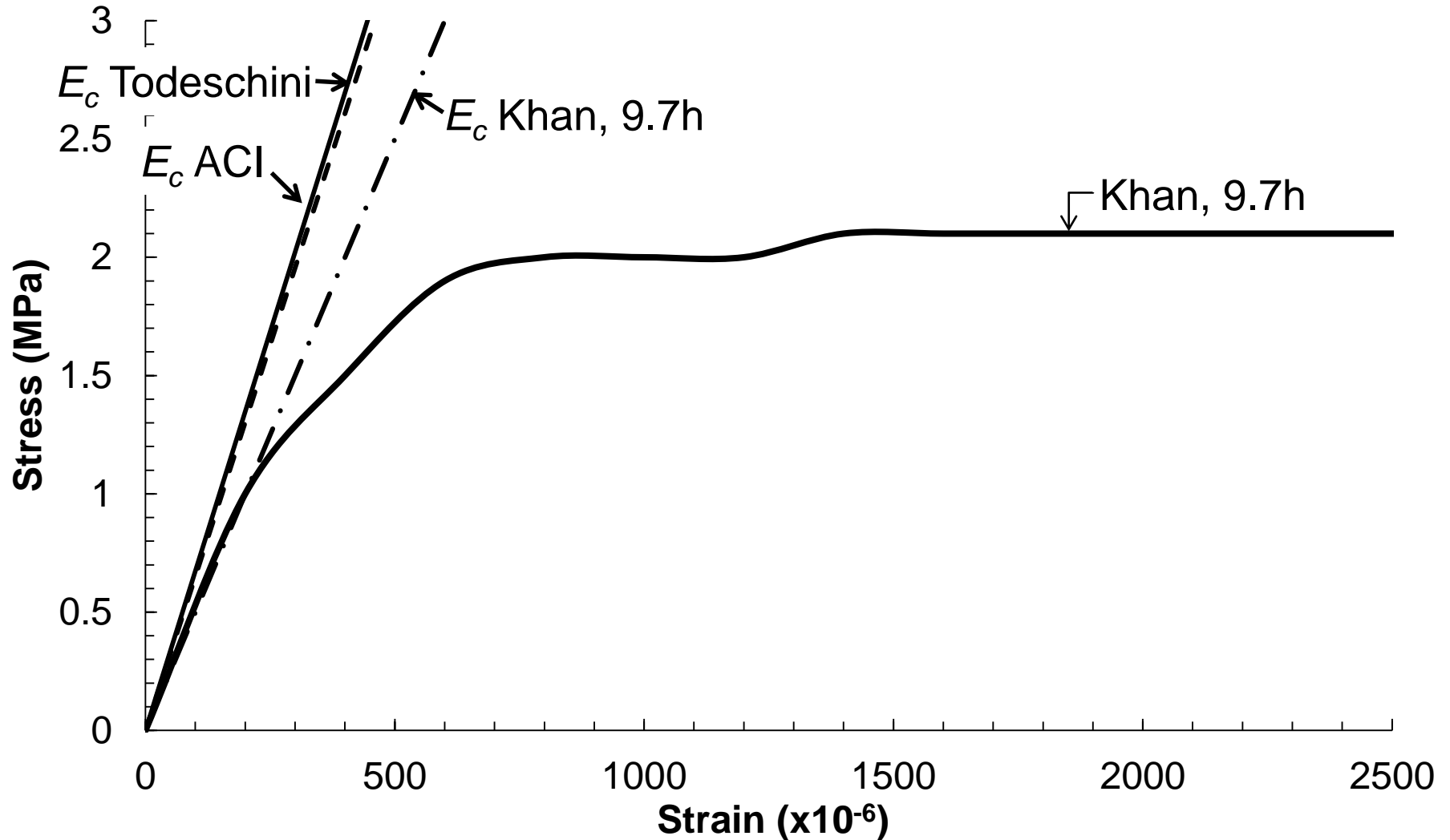
Early Age Secant Modulus



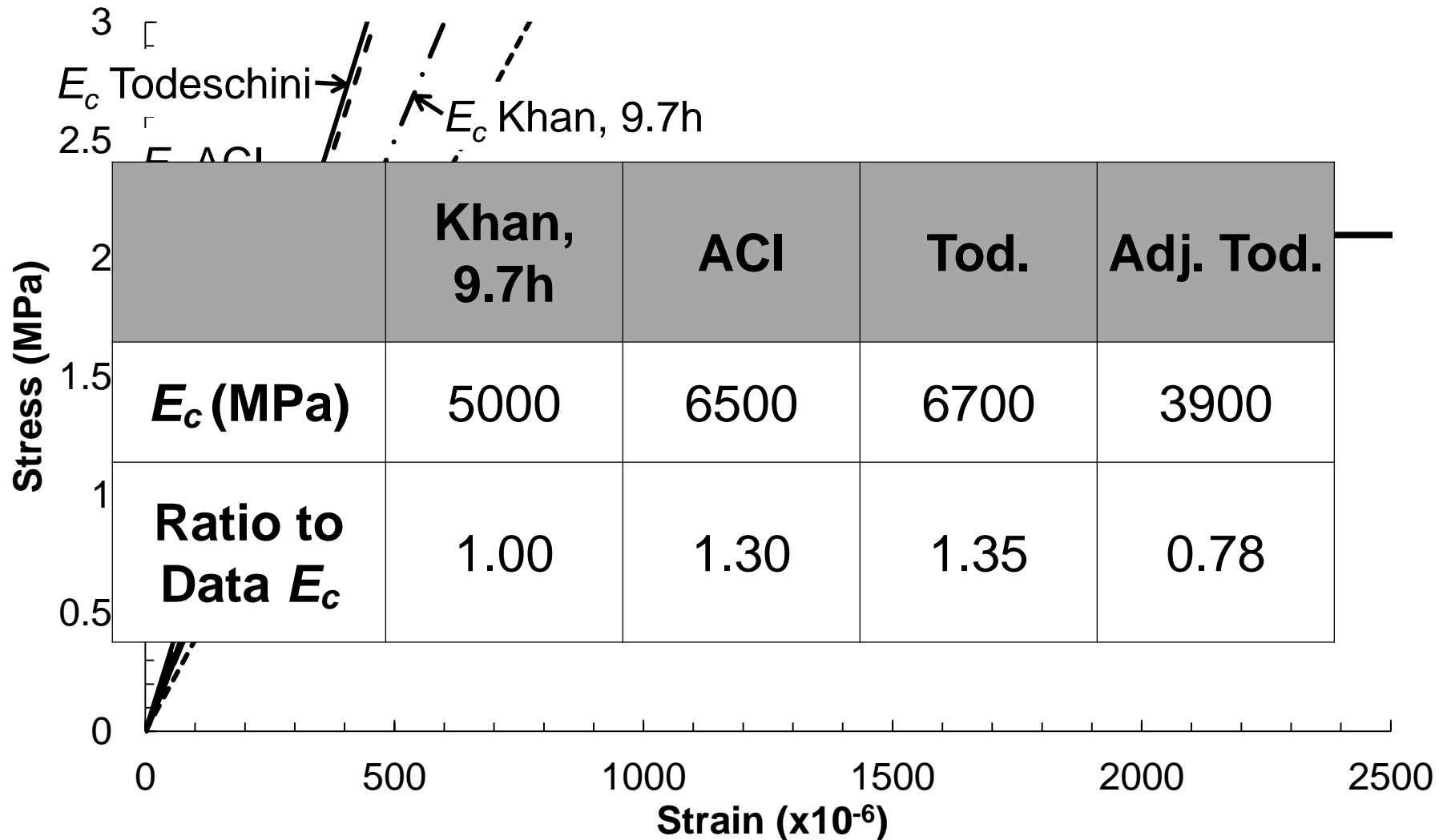
Early Age Secant Modulus



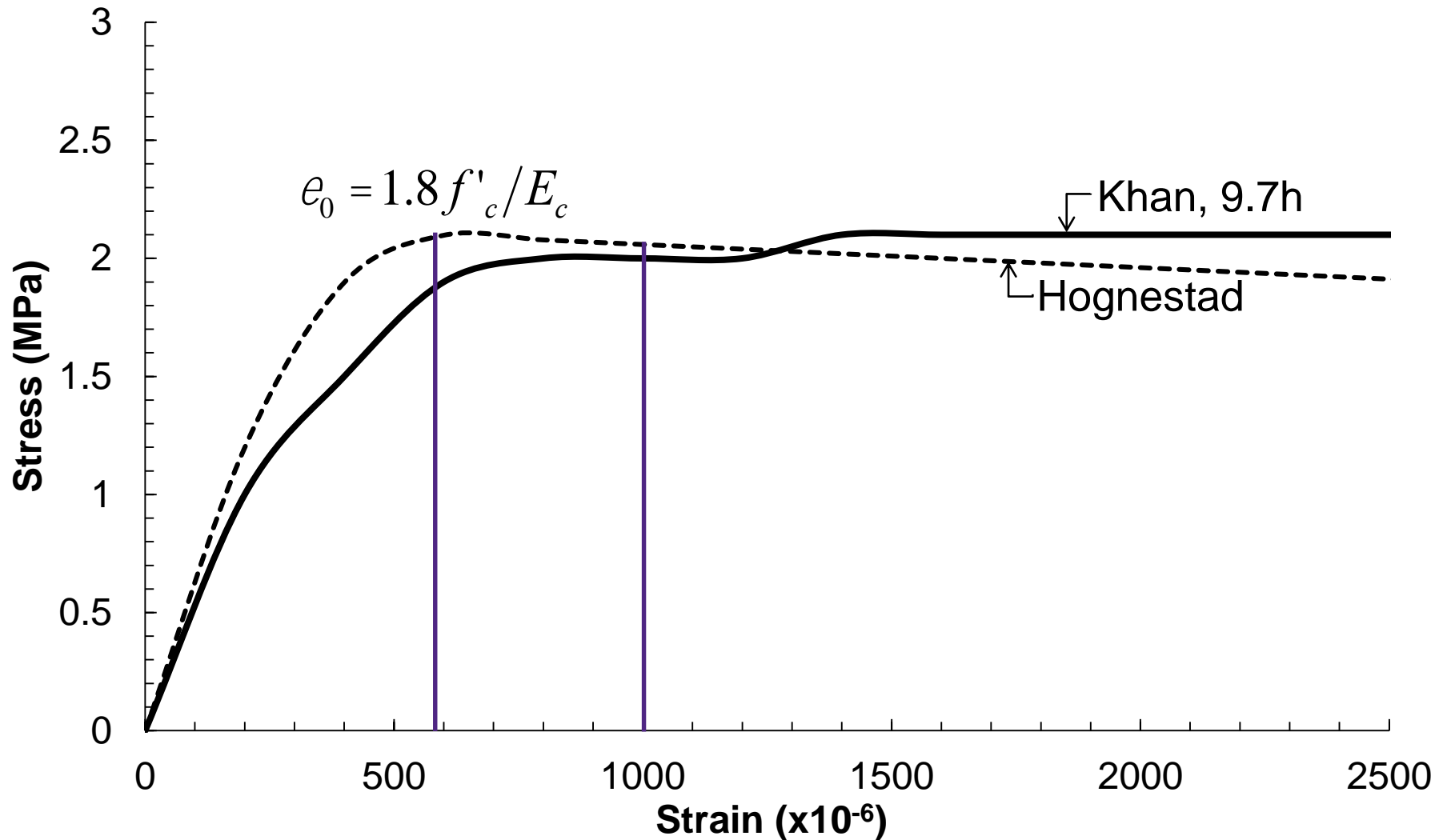
Early Age Secant Modulus



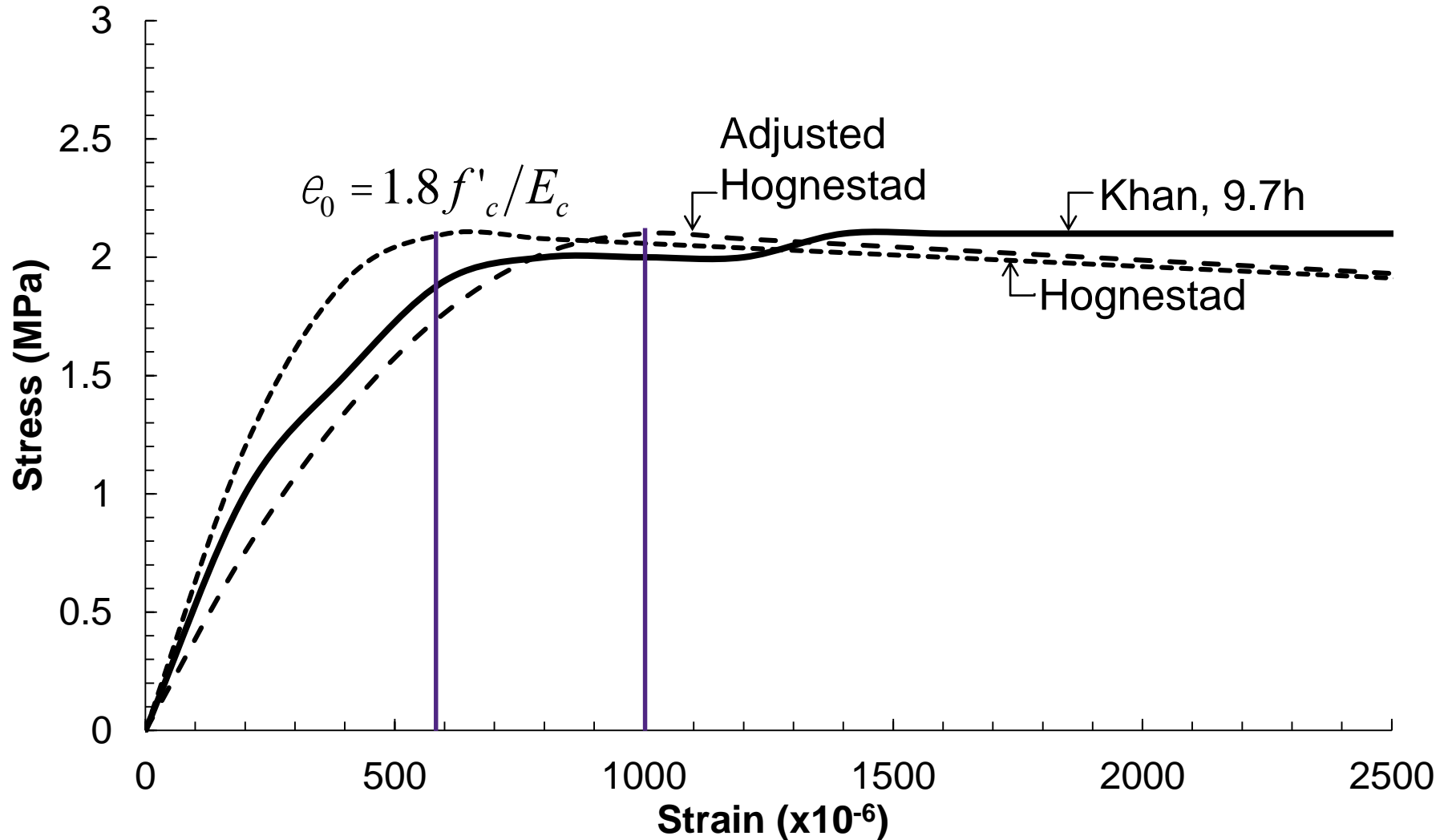
Early Age Secant Modulus



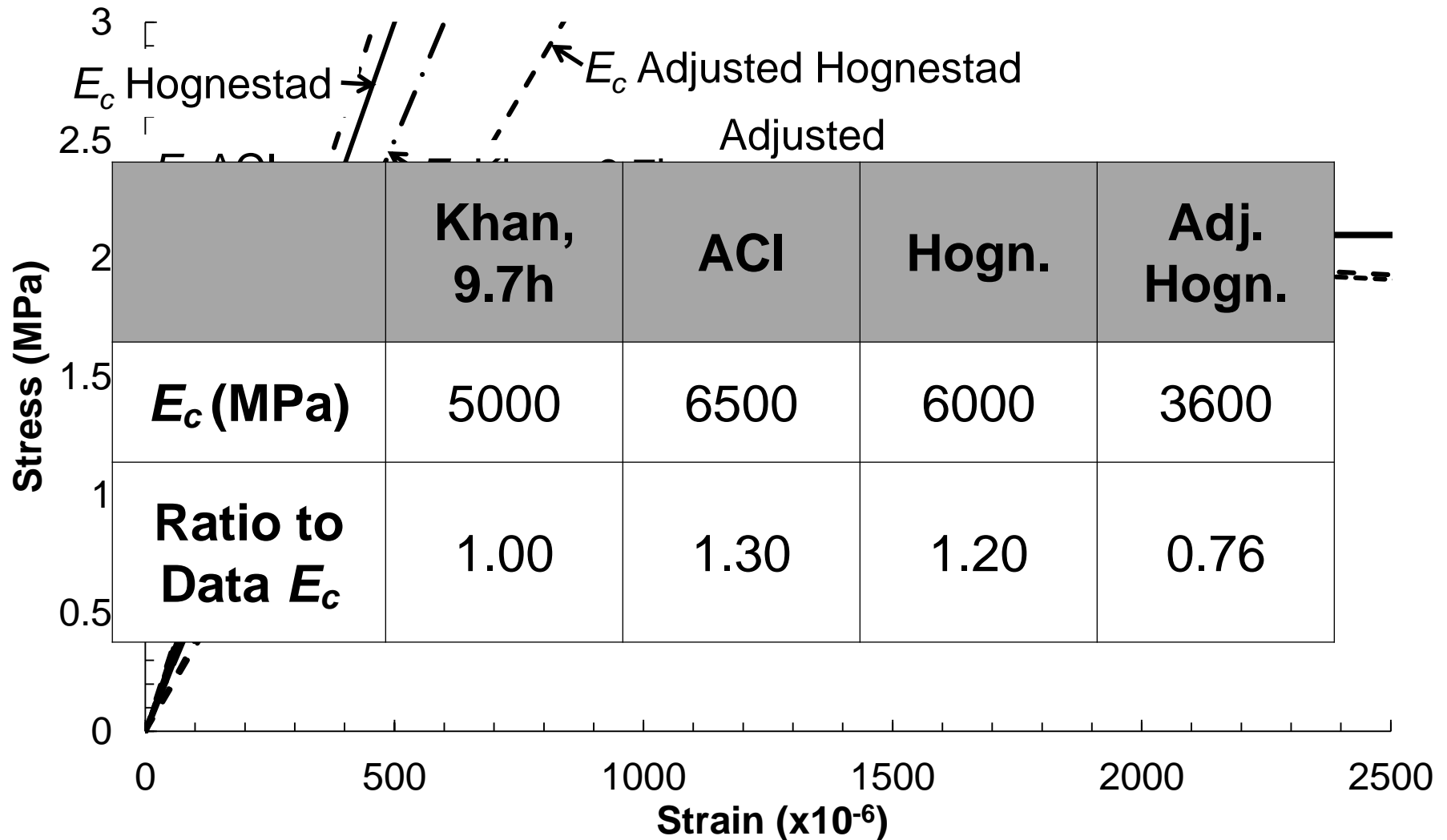
Hognestad at Early Ages



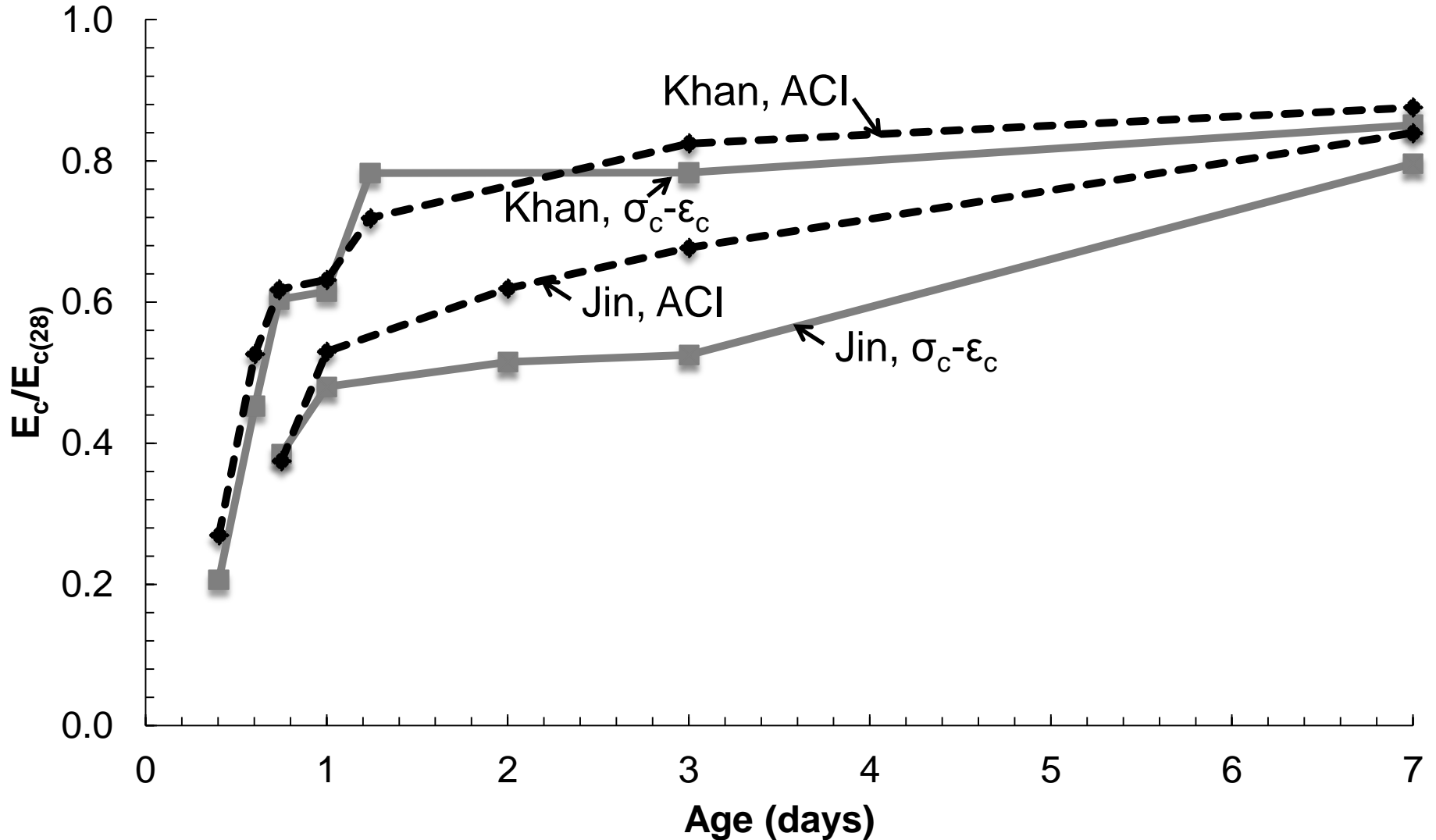
Hognestad at Early Ages



Hognestad at Early Ages



ACI Equation at Early Ages



Key Findings

1. Conventional relationships predict strain-softening that is not reflected in the data
2. Accuracy of conventional relationships depend heavily on ε_0
 - Using calculated ε_0 does not fit data well
 - Adjusted ε_0 will fit data but underestimates E_c
 - Challenging to determine appropriate ε_0
3. ACI equation overestimates E_c – unconservative for deflection calculations

Moment-Curvature Analysis

Parameters

- The parameters that were varied include:

- Material Properties

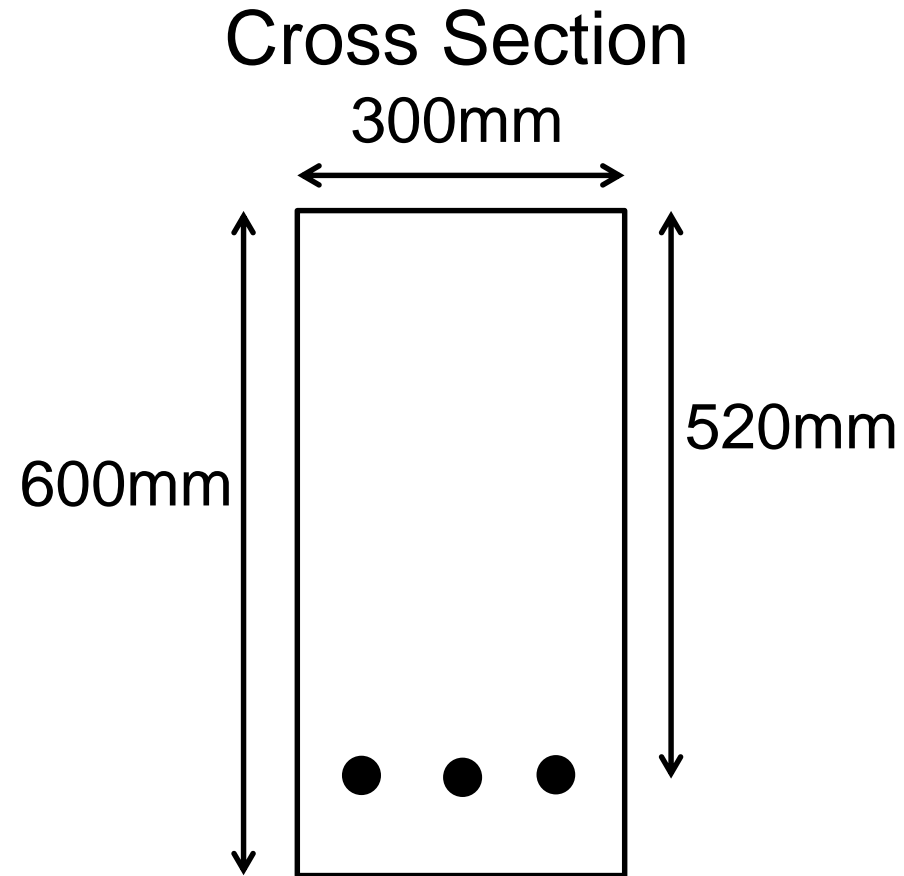
$$f'_c \text{ \& } E_c$$

- Age at Testing

$$t = 9.7 \text{ hrs to } 28 \text{ days}$$

- Reinforcement Ratio

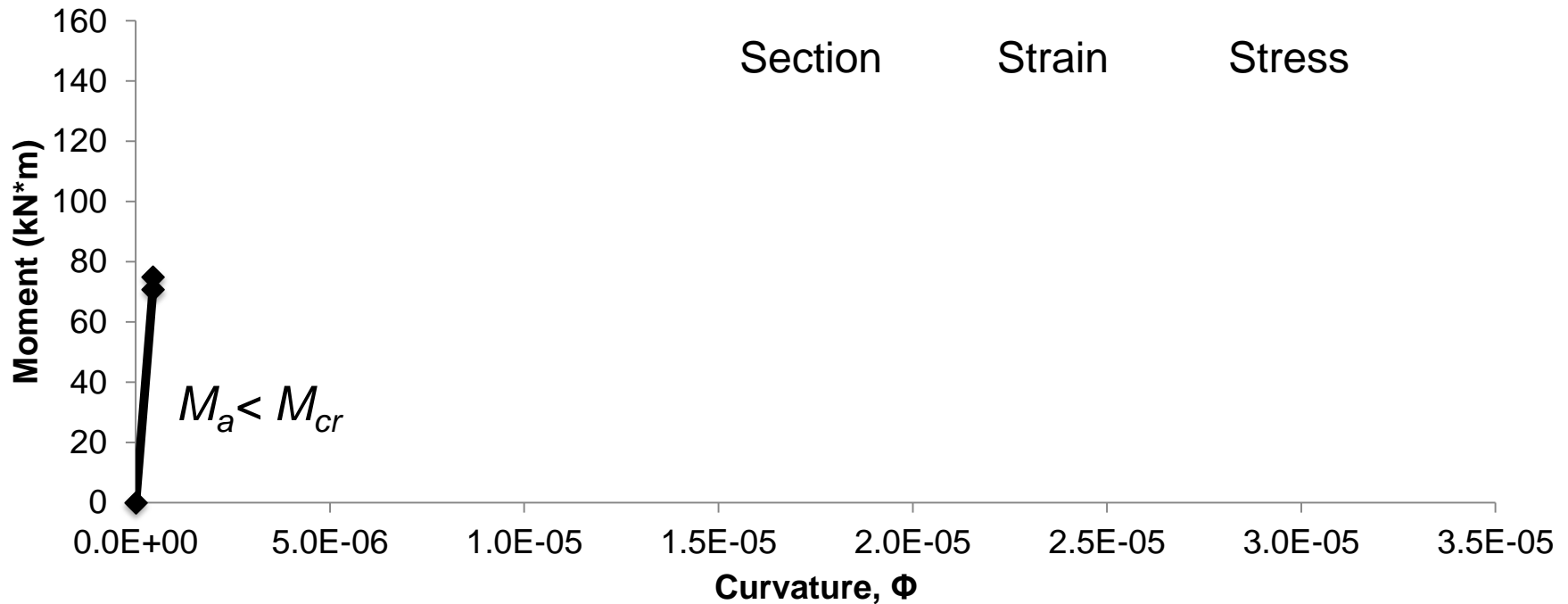
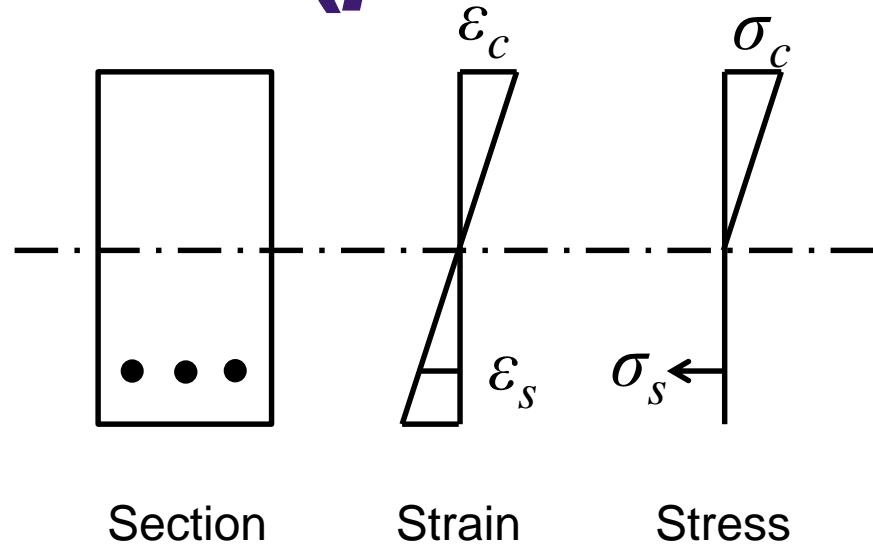
$$\rho = 0.5\%, 1.0\% \text{ \& } 2.0\%$$



3-Stage Approx. ($\rho = 0.5\%$)

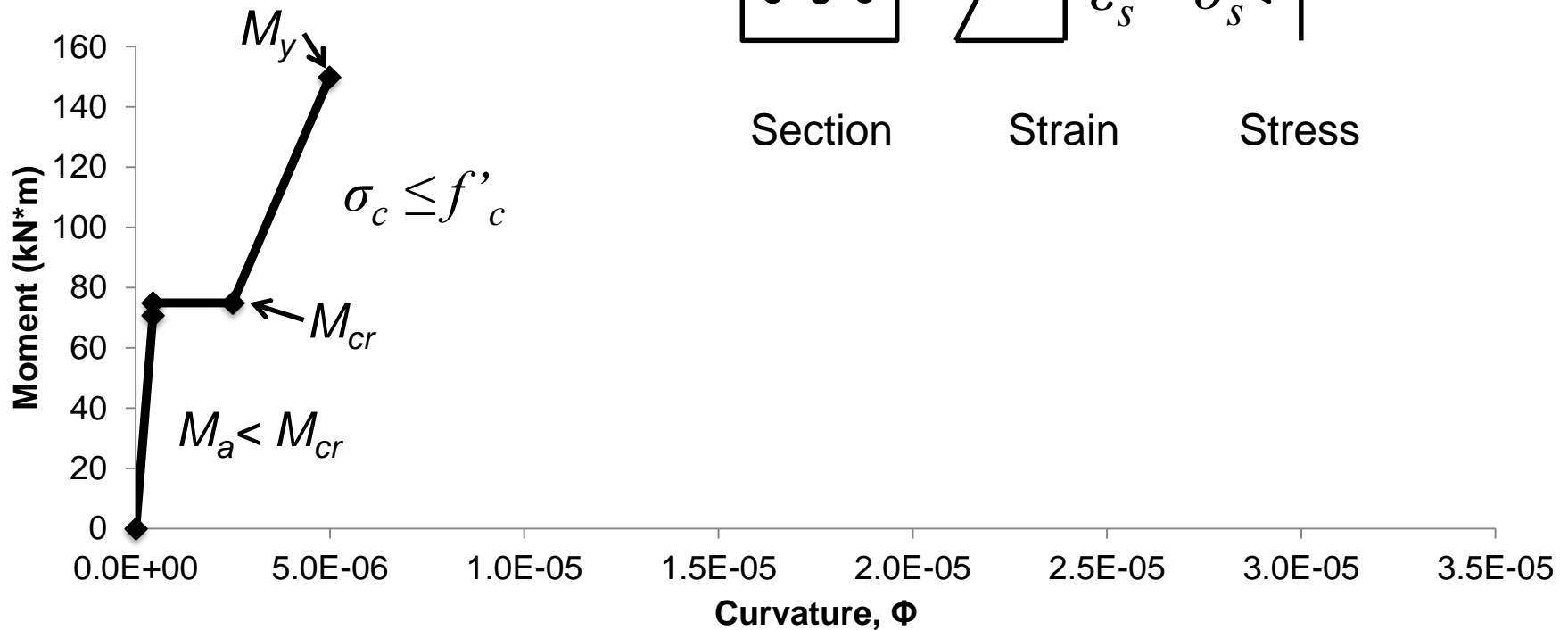
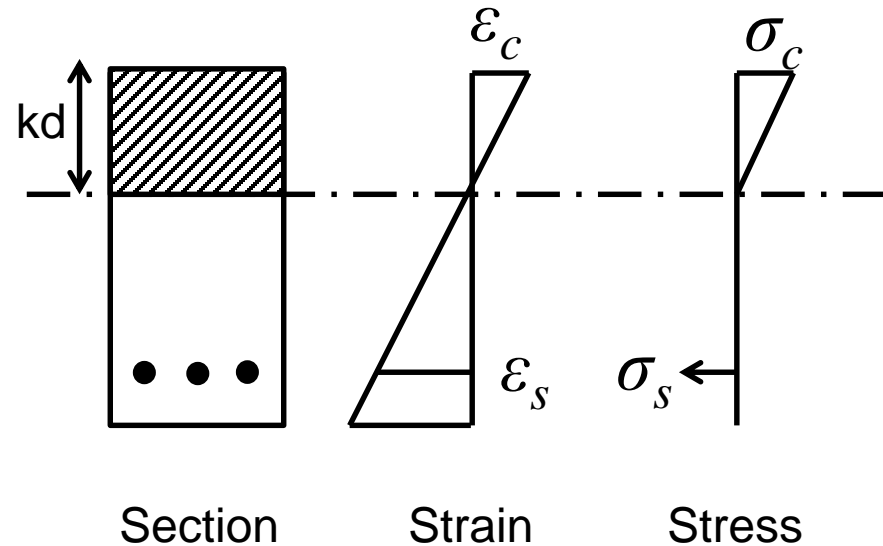
- Linear-Uncracked

$$n = 31 \text{ to } 8.4$$



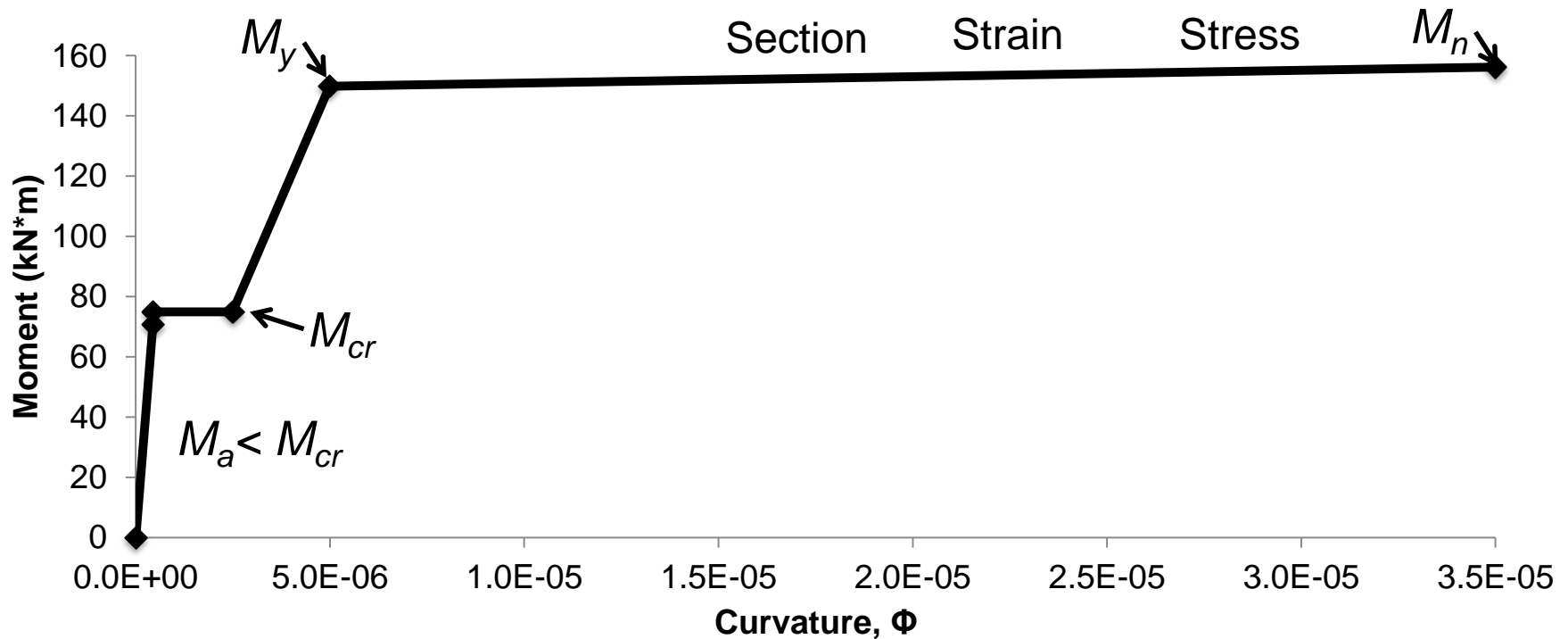
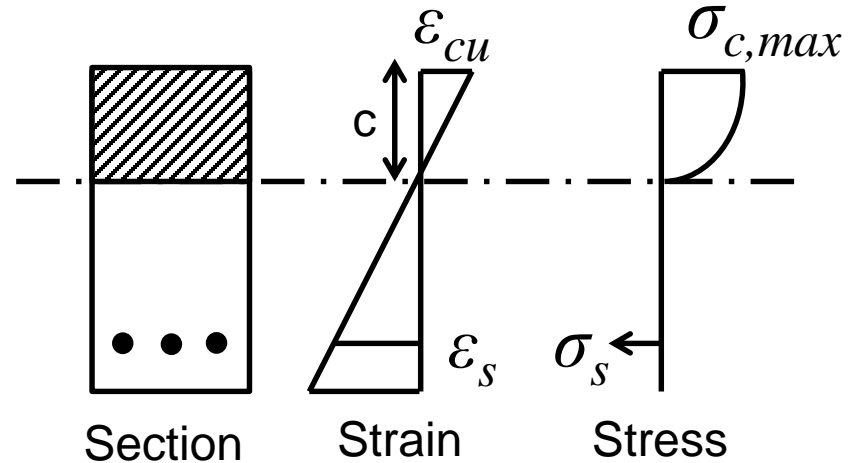
3-Stage Approx. ($\rho = 0.5\%$)

- Linear-Uncracked
- Linear-Cracked



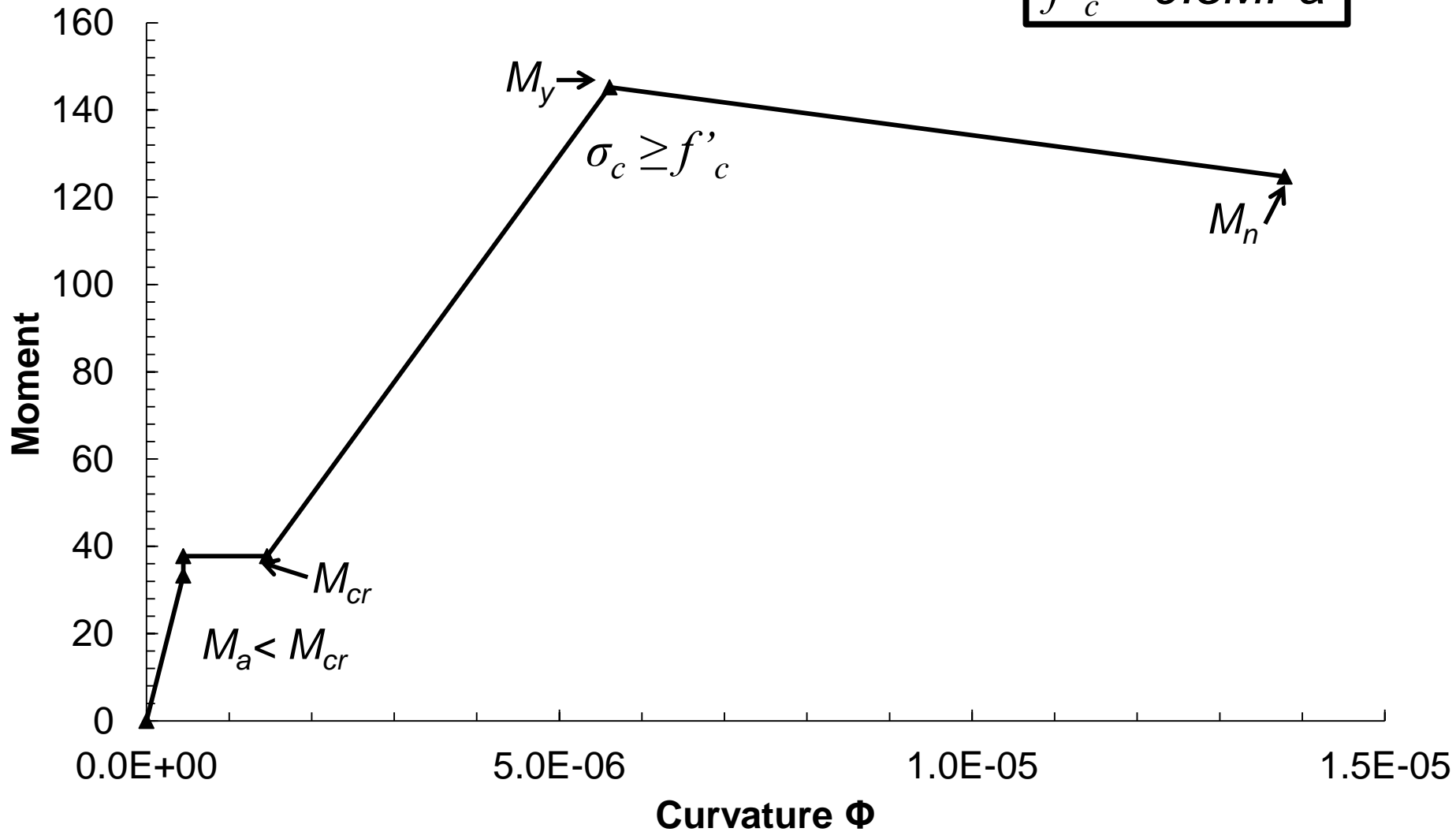
3-Stage Approx. ($\rho = 0.5\%$)

- Linear-Uncracked
- Linear-Cracked
- Nonlinear-Cracked

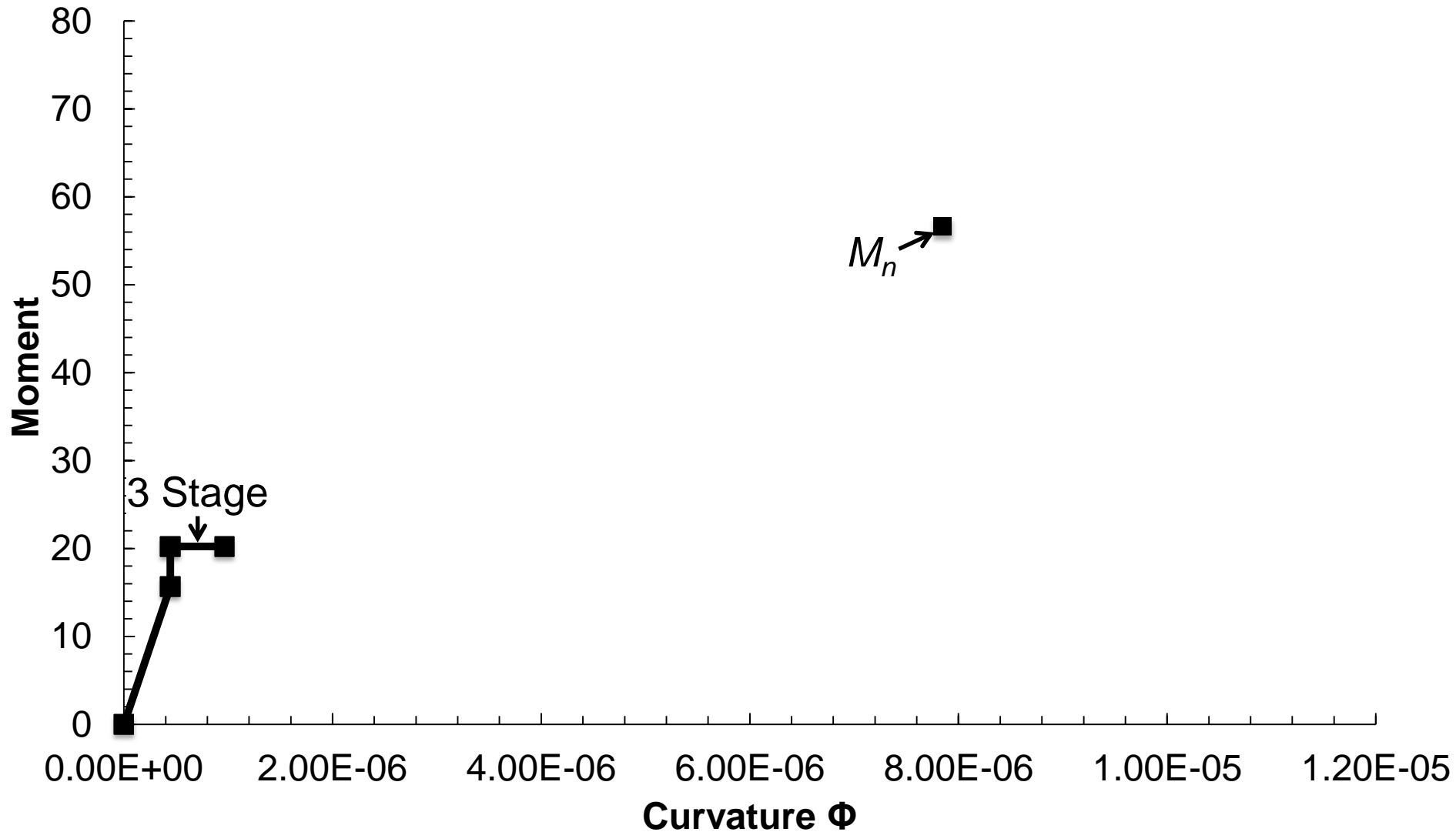


M- Φ at Early Ages

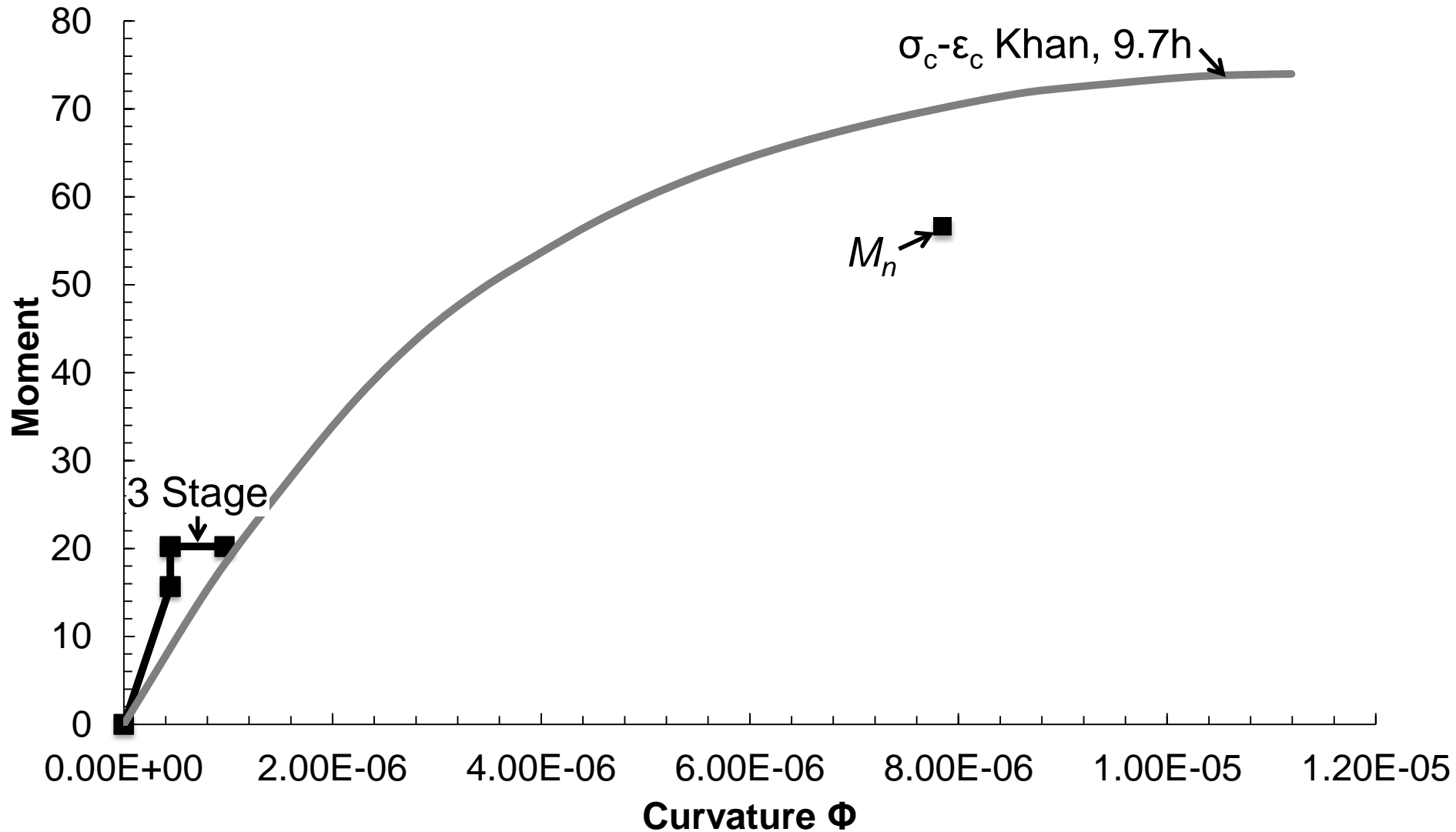
Jin, 18h
 $f'_c = 9.5\text{MPa}$



$M-\Phi$ at Early Ages

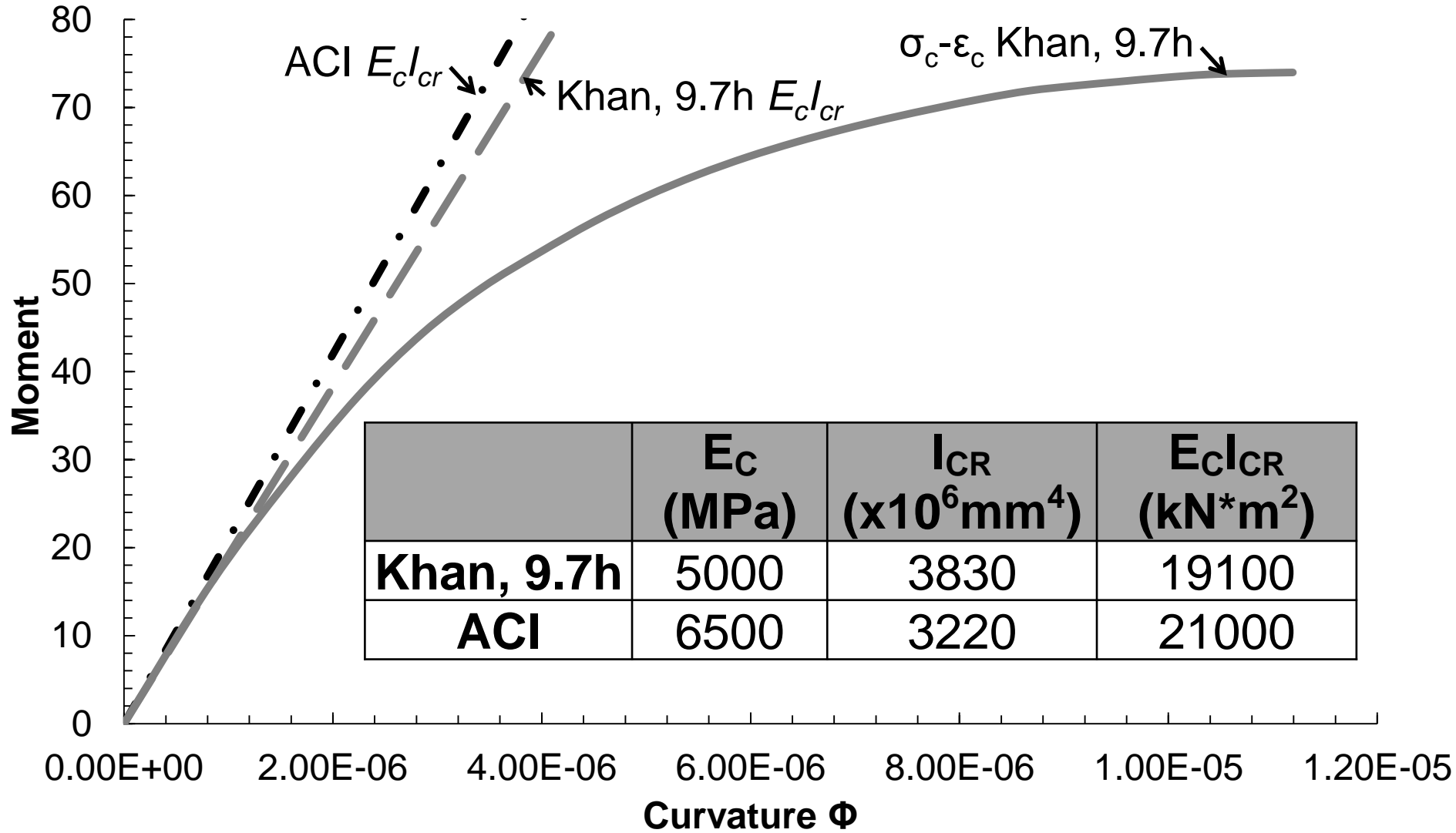


$M-\Phi$ at Early Ages

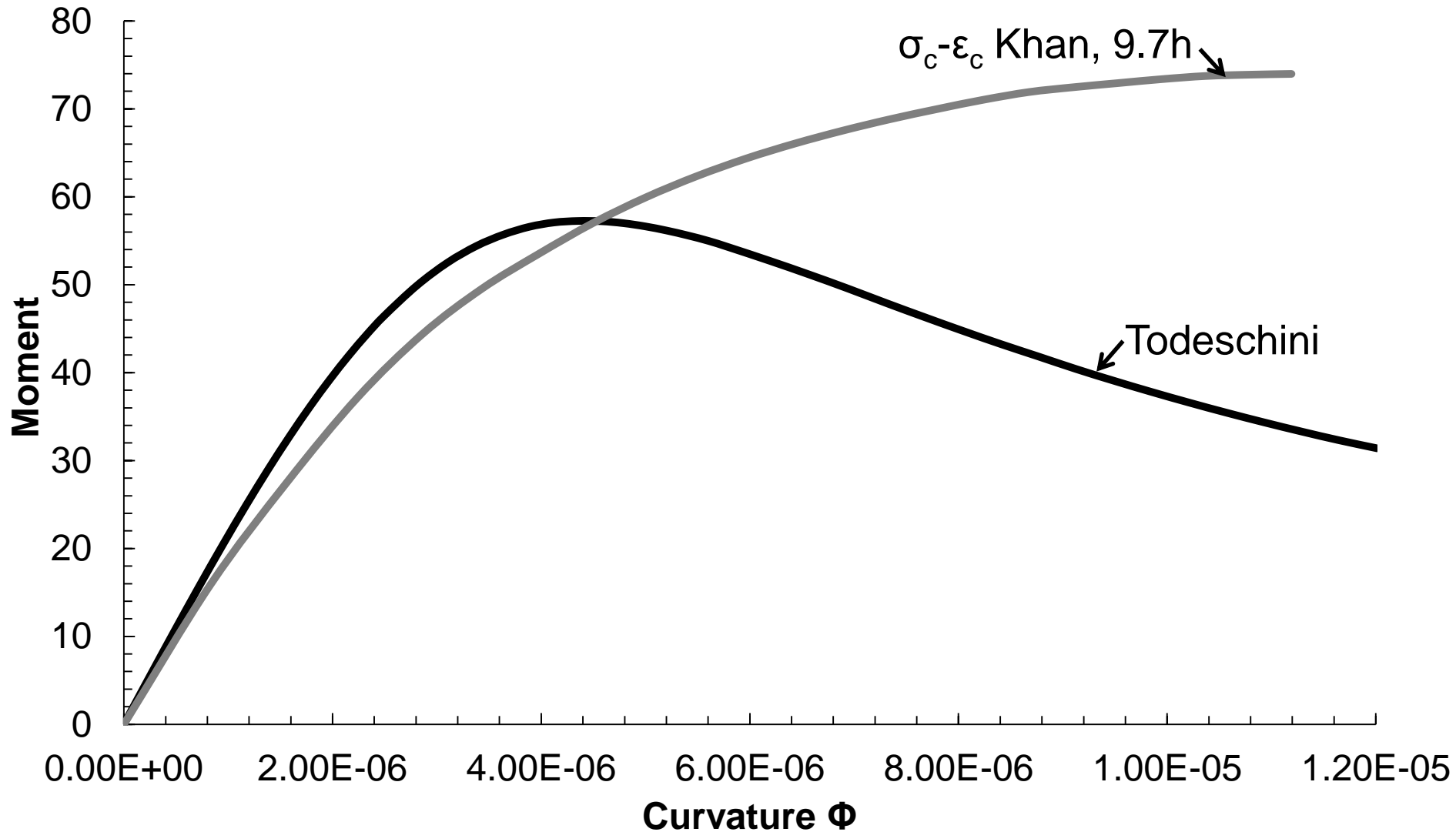


M- Φ at Early Ages

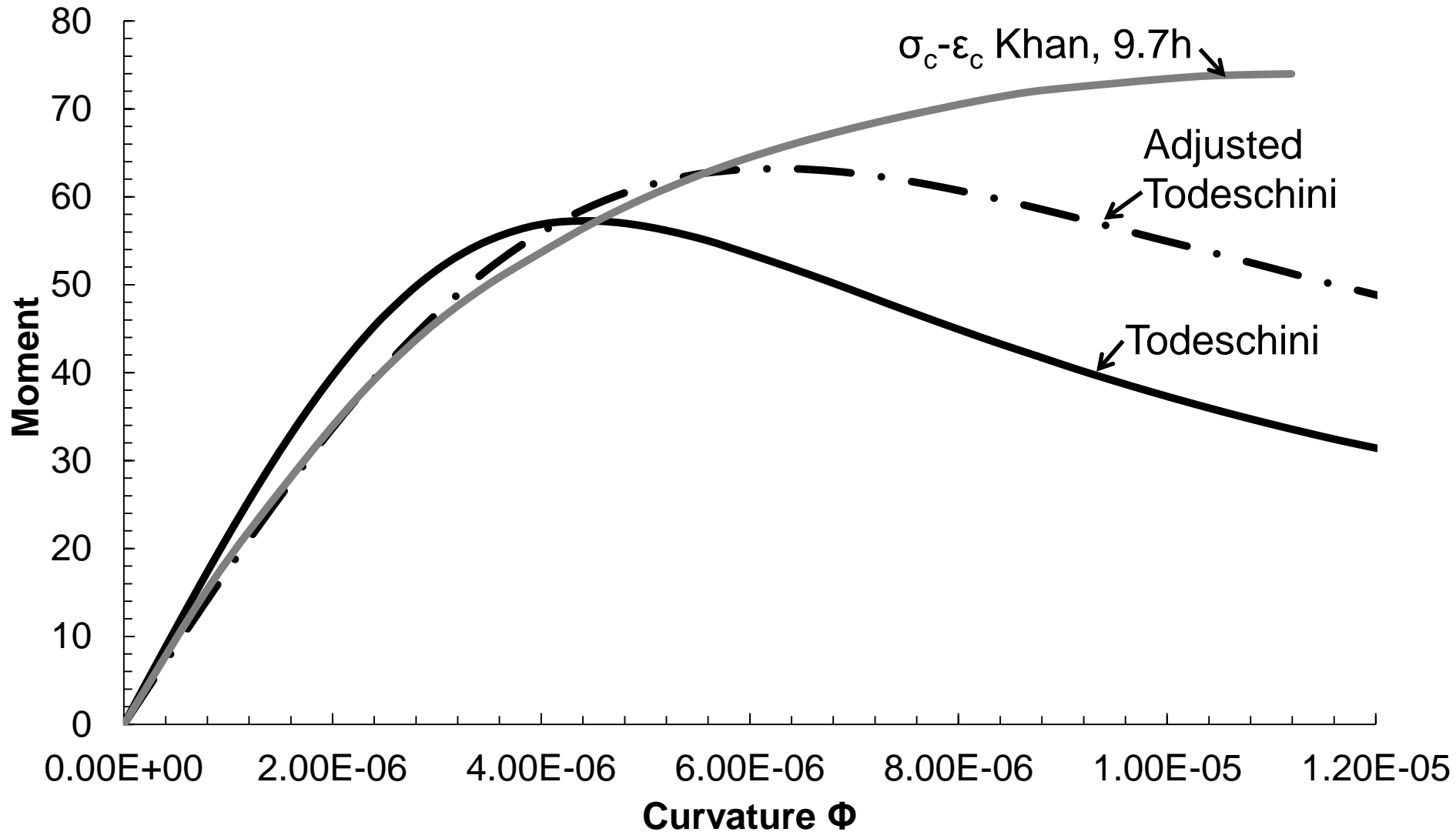
Khan, 9.7h
 $f'_c = 2.1\text{MPa}$



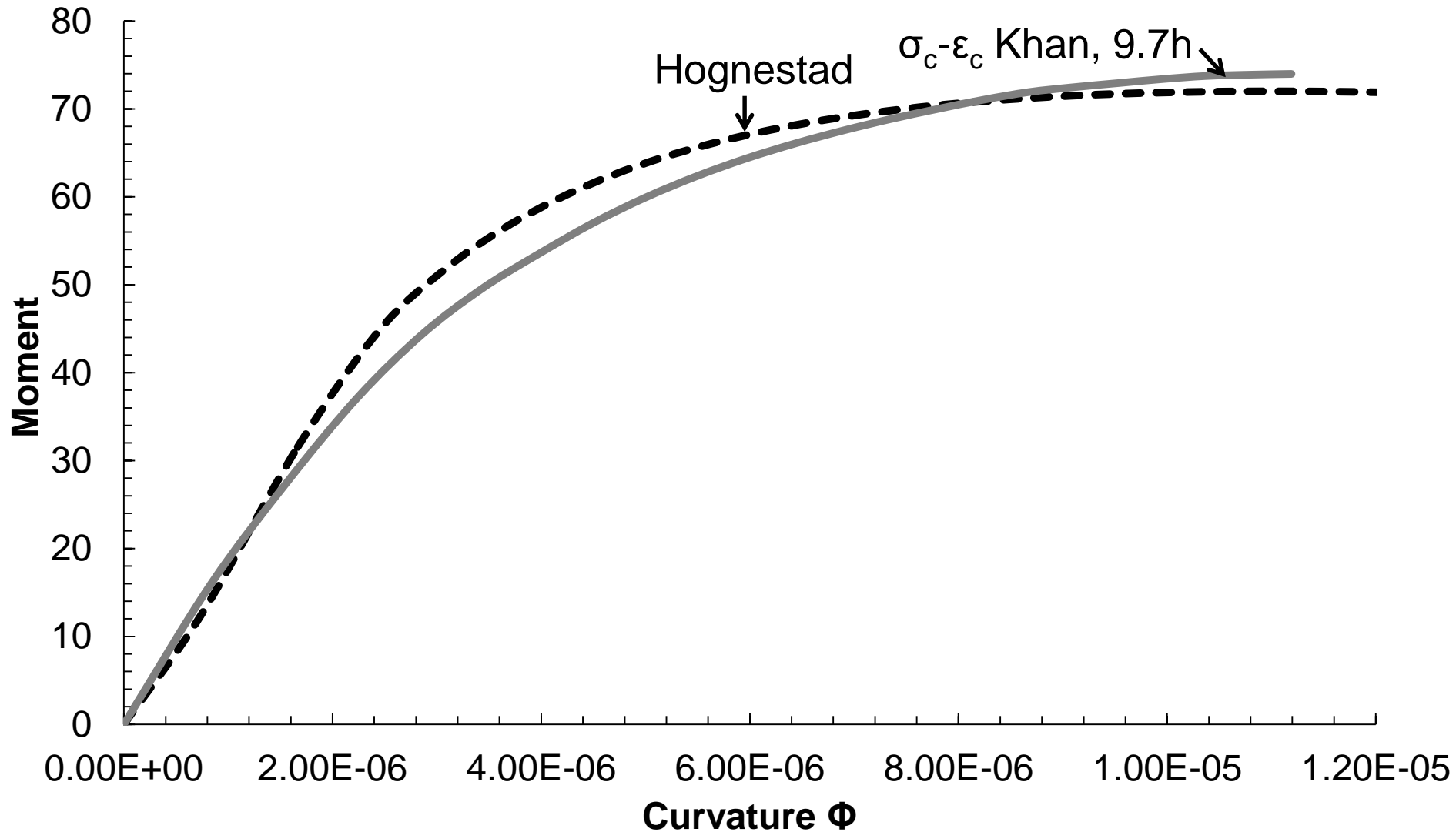
$M-\Phi$ at Early Ages



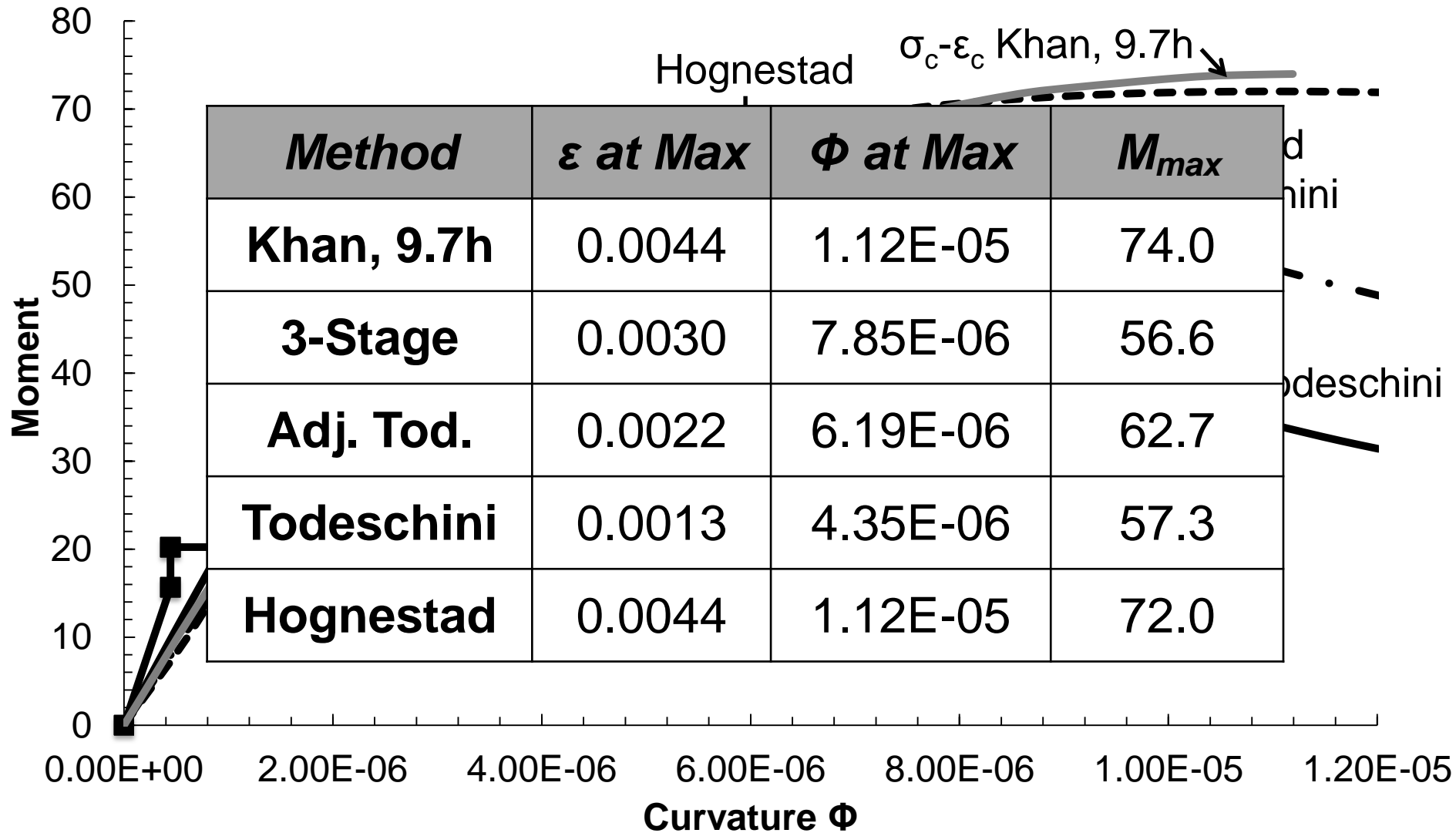
$M-\Phi$ at Early Ages



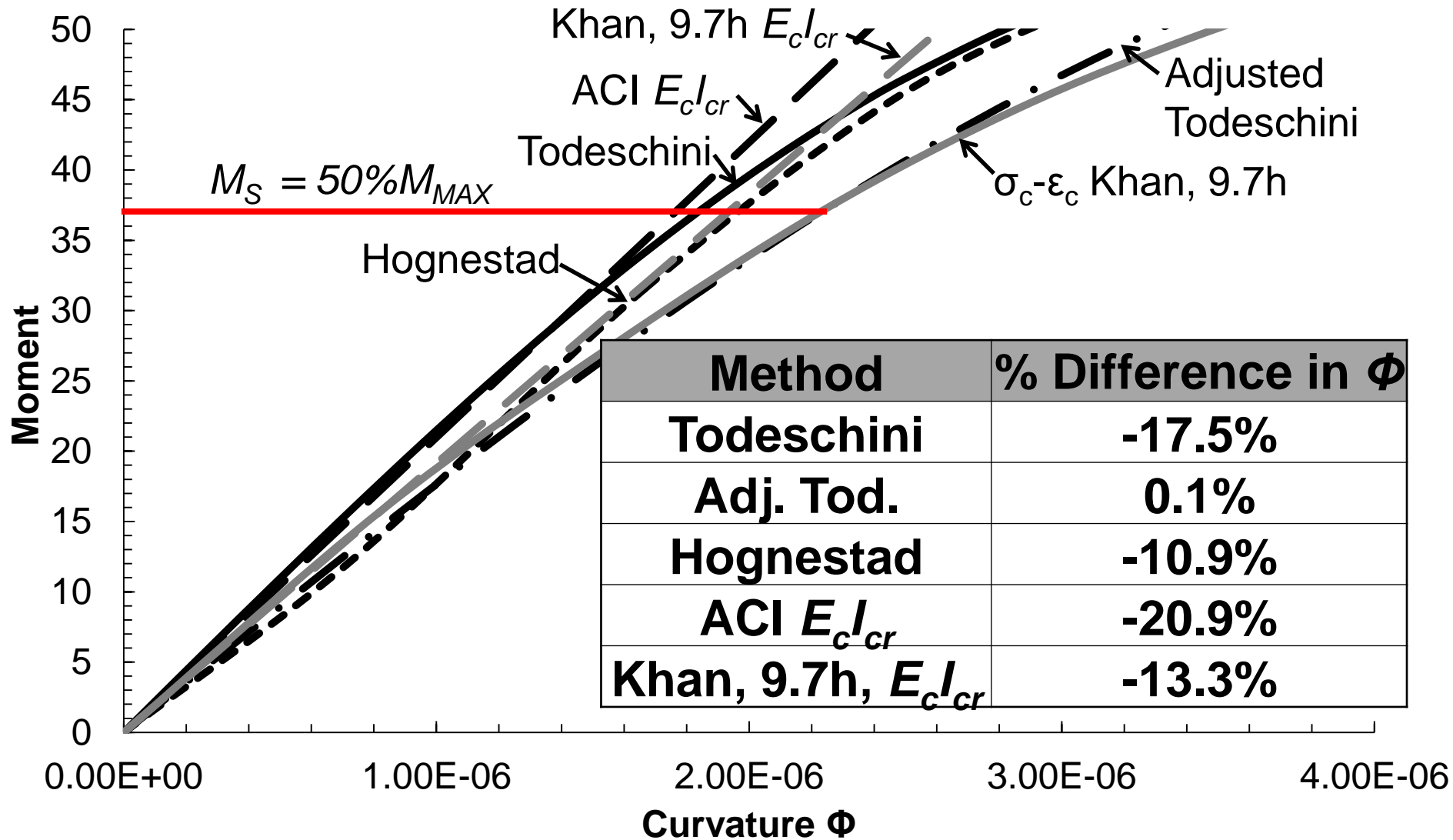
$M-\Phi$ at Early Ages



M- Φ at Early Ages



M- Φ at Service Loads

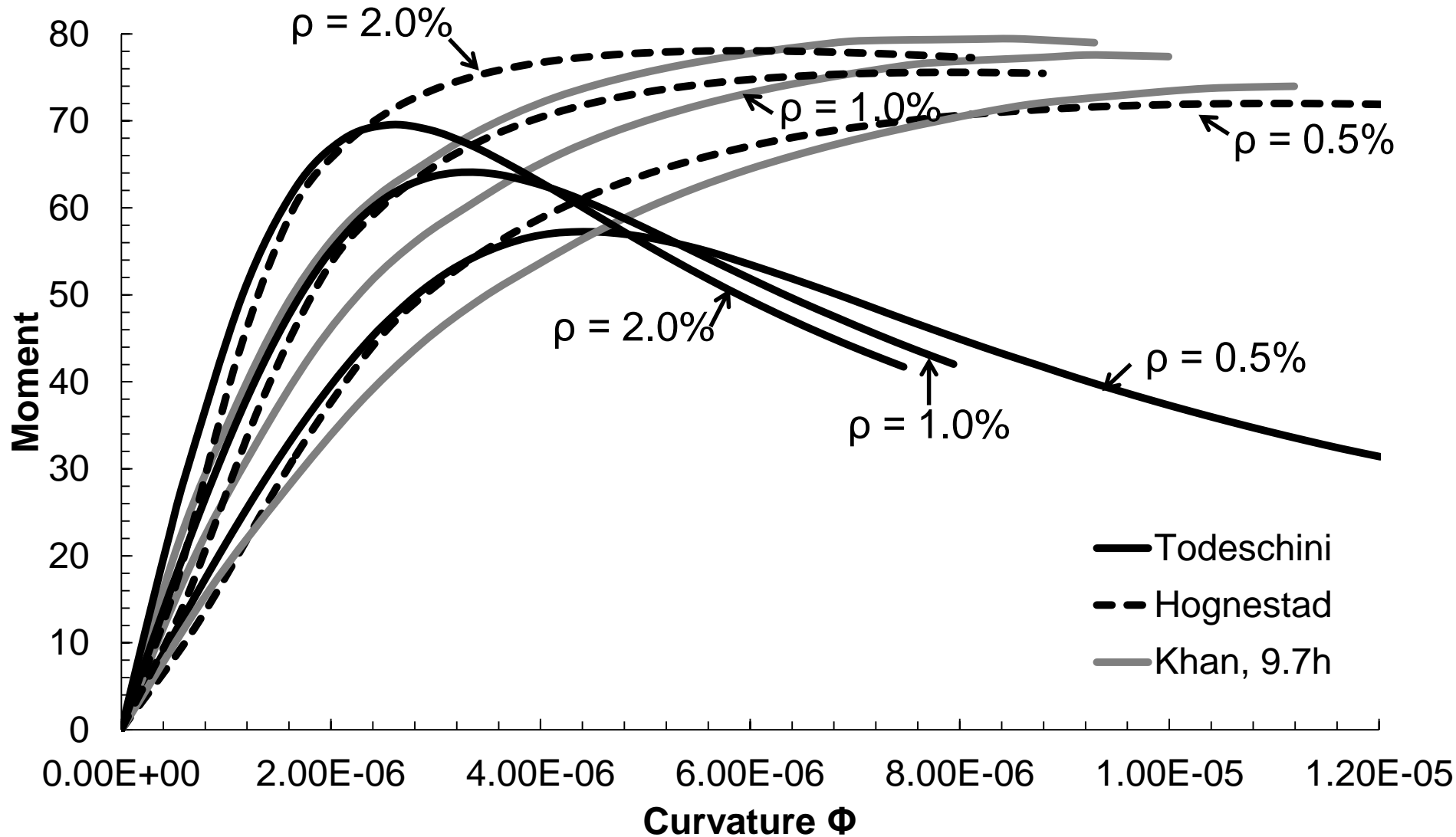


1 Day old $M-\phi$ at Service Loads

Khan, 1 day
 $f'_c = 11.5\text{MPa}$
38% 28 day strength

Method	% Difference in ϕ
Todeschini	-2.9%
Adj. Tod.	-1.2%
Hognestad	11.3%
ACI $E_c I_{cr}$	-0.8%
Khan, 1d, $E_c I_{cr}$	-0.2%

Effect of ρ



Effect of ρ on $E_c I_{cr}$

		$E_c I_{cr} / (\text{Khan, 9.7h})$		
Age	ρ	ACI	Todeschini	Hognestad
9.7h ($f'_c = 2.1$ MPa)	0.5%	1.10	0.91	1.07
	1.0%	1.13	0.88	1.09
	2.0%	1.17	0.85	1.11
14.5h ($f'_c = 8.0$ MPa)	0.5%	1.04	0.96	1.03
	1.0%	1.05	0.95	1.03
	2.0%	1.07	0.93	1.05
17.7h ($f'_c = 11.0$ MPa)	0.5%	1.01	0.97	1.00
	1.0%	1.01	0.96	0.99
	2.0%	1.01	0.95	0.99
1d ($f'_c = 11.5$ MPa) 38% $f'_{c(28)}$	0.5%	1.01	1.01	1.00
	1.0%	1.01	1.01	0.99
	2.0%	1.01	1.01	0.99

In Conclusion

1. Shape of stress-strain curve at young ages does not exhibit strain softening
2. Conventional stress-strain models predict strain-softening and depend heavily on ε_0
3. Equations for strain at maximum stress do not work well for young concretes
4. ACI equation overestimates E_c at young ages – unconservative for deflections

In Conclusion

5. Some idealizations do not apply to young concrete, inadmissible if f'_c is exceeded
6. Moment-curvature response based on $E_c I_{cr}$ valid at young ages

Next Steps

- More comparisons to experimental studies by others
- Time-dependent deflections of concretes loaded at very young ages

Acknowledgments

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- ACI Foundation
- Western University

References

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