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# Field Measurements of Form Pressure Exerted by Self-Consolidating Concrete

**ACI Spring 2013 Convention**
**April 14 - 16, Minneapolis, MN**

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## *Effect of Material Constituents & Mix Design Parameters on Thixotropy and Form Pressure for SCC*

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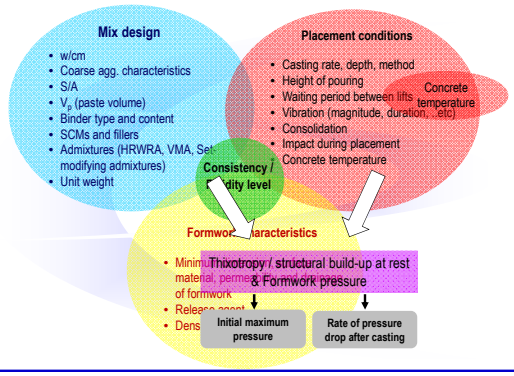
*Kamal Khayat, Missouri University of Science & Technology*

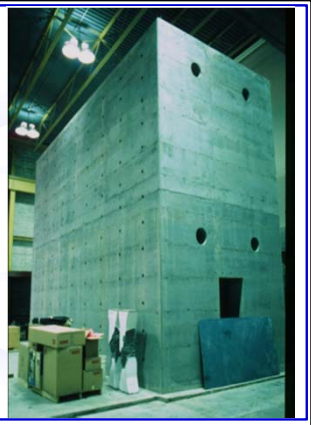
*ACI Spring Convention*
*Minneapolis-Minnesota-USA*
*April 14th 2013*

## Factors influencing formwork pressure





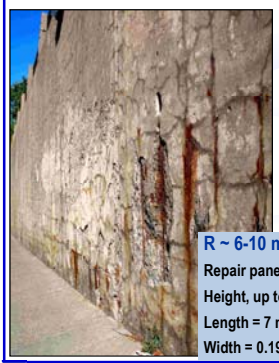

## Casting Rate



R ~ 1 m/hr
Lift height = 3.5 m
Thickness = 0.9 m
Length x width = 9 x 4 m



## Rehabilitation of retaining walls



R ~ 6-10 m/hr
Repair panels
Height, up to 7 m
Length = 7 m
Width = 0.19 m

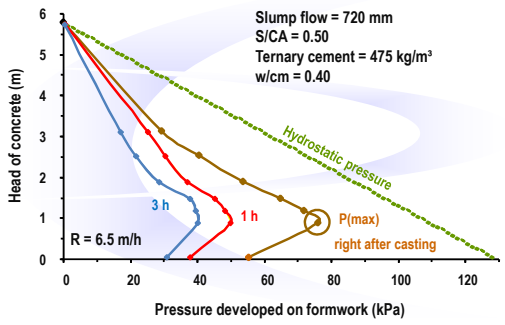


## Validation of Role of Thixotropy on Form Pressure

Sand/CA = 0.44, 0.5, 0.54
HRWRA: PCP vs. PNS
Cement: Tenary vs. Binary
Effect of synthetic fibers

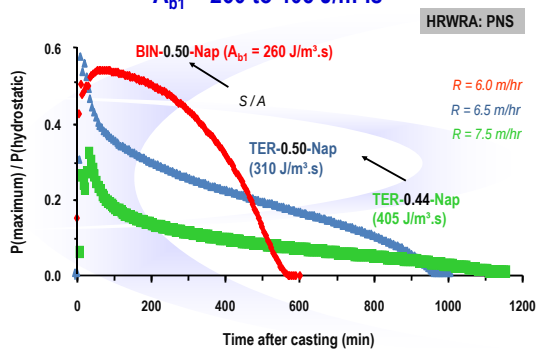


## Typical Formwork Pressure Diagram



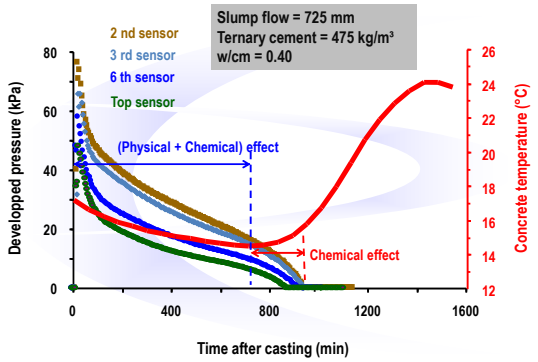



## Pressure Variations with Thixotropy
## $A_{b1}$ = 260 to 405 J/m³.s



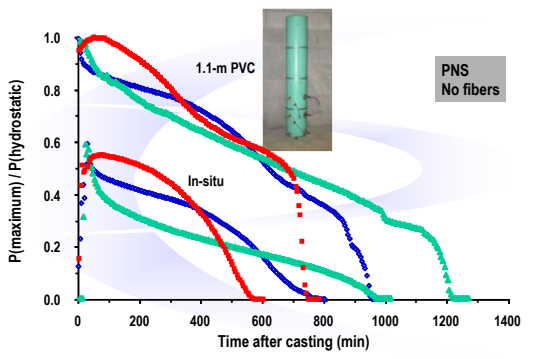



## Variations in Pressure until Cancellation






## Pressure Decay Comparison



## Thixotropy as Input to Evaluate Form Pressure for SCC

$$P_{max} = \rho g H [a_1 H + a_2 R + a_3 T + a_4 D_{min} + a_5 TI_{@fixed\ Temp.}]$$

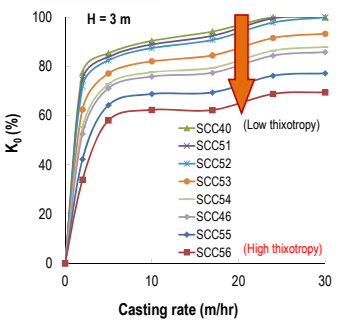
- ρ: unit weight of SCC
- H: casting depth in the form
- R: casting rate
- T: concrete temperature
- $D_{min}$: formwork width
- **TI**: thixotropy index



## Effect of casting rate & thixotropy on lateral pressure characteristics

SCC lateral pressure can be reduced by:

lowering casting speed, or increasing thixotropy

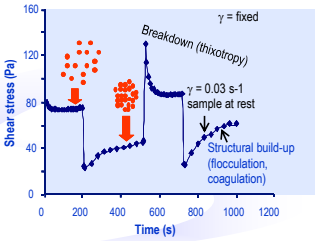


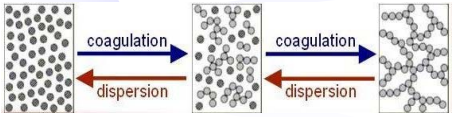



## Thixotropy

is a decrease in time of viscosity under constant shear stress or shear rate, followed by a gradual recovery when the stress or shear rate is removed (Barnes, 1997).

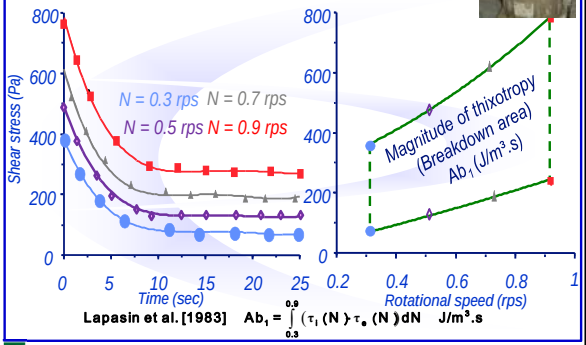
a reversible phenomenon





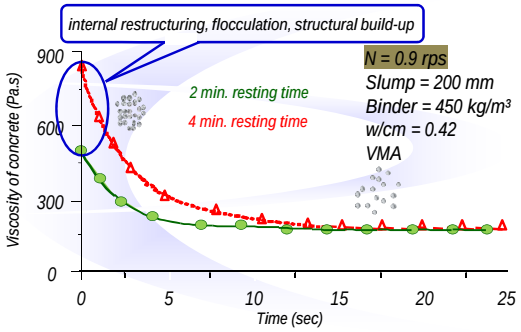

## Testing Protocol of Thixotropy : breakdown curves




Lapasin et al. [1983] $Ab_1 = \int_{0.3}^{0.9} (\tau_i(N) - \tau_e(N))\,dN$ J/m³.s



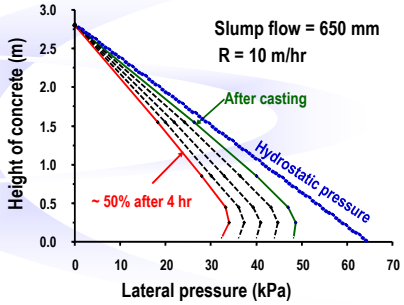
## Importance of internal restructuring



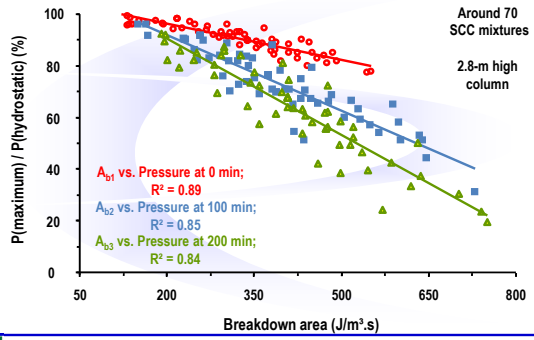



## Rigid PVC Column to Determine Lateral Pressure Envelope

H = 2.8 m
D = 0.2 m
R = 5, 10, 25 m/hr

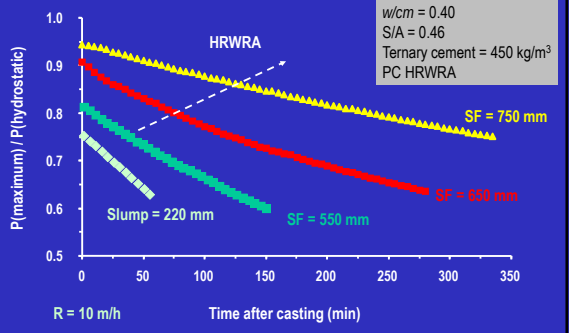



## Thixotropy vs. Lateral Pressure

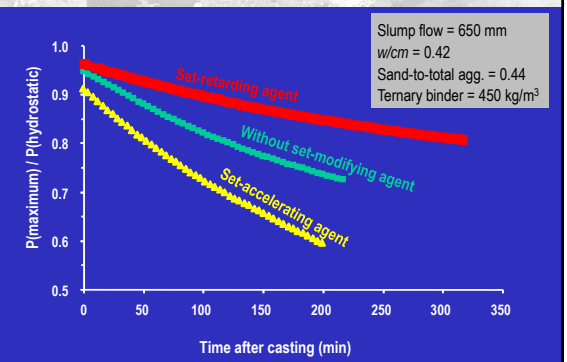




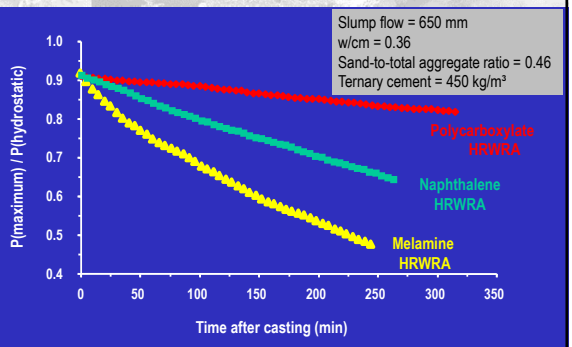

## Effect of Consistency Level



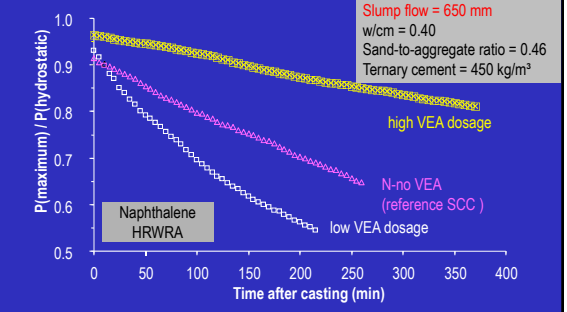

## Effect of Set-Modifiers (Cohesion)




## Effect of HRWRA Type

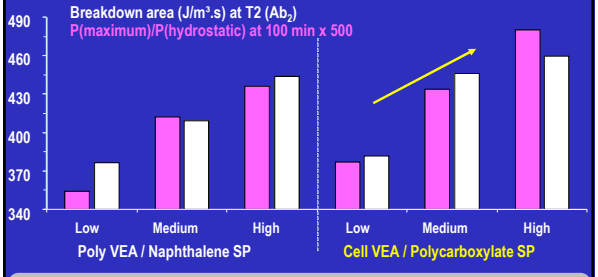



## Effect of powder polysaccharide-based VEA content (SP dosages variable)



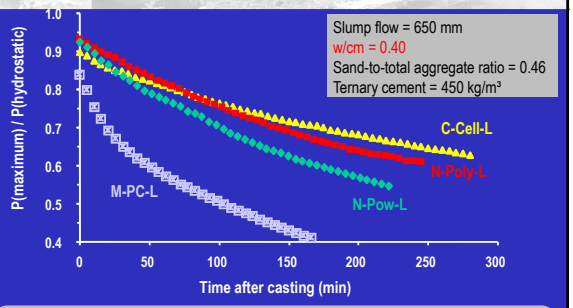

Incorporation of low thickener VEA in SCC with 0.40 w/cm can lead to lower lateral pressure than in SCC with no VEA

## $Ab_2$ vs. $K_{0@100\ min}$ for SCC with different dosages of Poly or Cell VEA (SP constant)



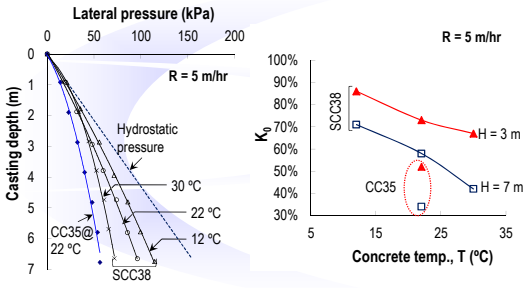

- Medium or high content of **poly**saccharide-based VEA + PNS-based HRWRA resulted in higher residual pressure and lower rate of pressure drop after casting compared to SCC with low dosage of VEA (attributed to increased HRWRA demand)
- Similar results with **cel**lulose VEA + polycarboxylate-based HRWRA

## Effect of Thickner Type (low concentration)



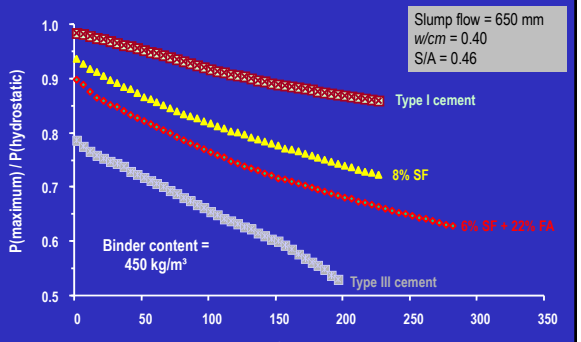

- Mixtures incorporating TEA exhibited the lowest initial pressure and the fastest rate of pressure drop
- Unlike conventional VEA, increase in TEA lead to further reduction in initial pressure and increased rate of drop in pressure

## Effect of concrete temperature on lateral pressure characteristics

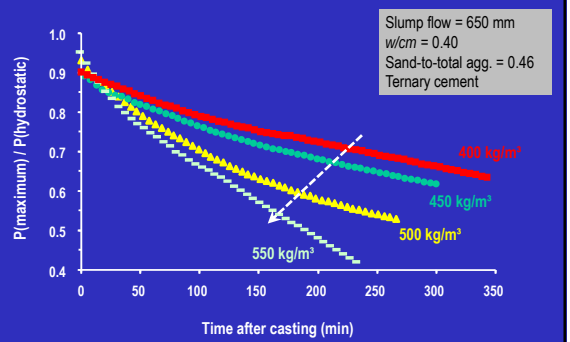




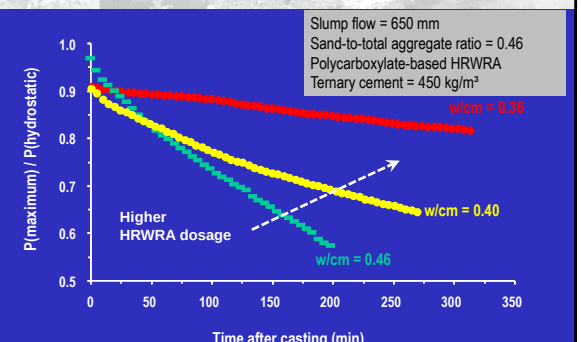

## Effect of Binder Type



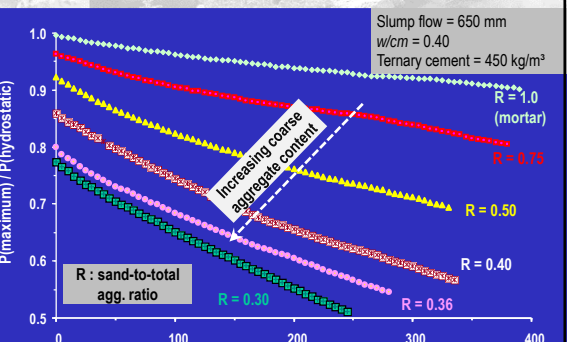

## Effect of Binder Content




## Effect of *w/cm*




## Effect of S/A (Internal Friction)



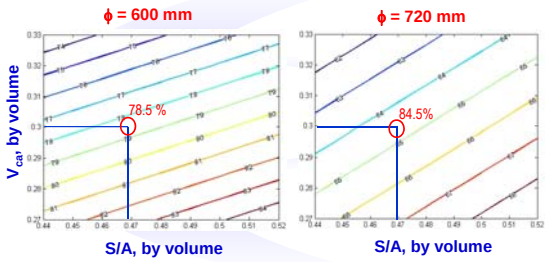
## Effect of [$\phi$, $V_{ca}$, S/A] on [$K_{0@Hi}$, $\Delta K(t)$, $t_c$] using statistical models

| | Units | Predicting model in CODED values ($\phi$, $V_{ca}$, S/A ) = -1 to +1 | $R^2$ | Relative error 95% conf. limit (%) |
|---|---|---|---|---|
| $K_0$ at various H | % | $K_{0@H=4\ m} = 82 - 3.175\ V_{ca} - 3.015\ \phi + 1.6875\ S/A + 0.9\ \phi.\ V_{ca}$ | 0.94 | 2.4 |
| | % | $K_{0@H=8\ m} = 67.2 - 4.7275\ V_{ca} + 4.0675\ \phi + 1.96\ S/A + 1.1775\ \phi.\ V_{ca}$ | 0.94 | 2.3 |
| | % | $K_{0@H=12\ m} = 53.5 - 6.2775\ V_{ca} + 5.1175\ \phi + 2.2325\ S/A$ | 0.91 | 4 |
| $\Delta K(t)$ | %/min | $\Delta K(t)(0\text{-}60min) = 0.1683 + 0.0325\ V_{ca} - 0.0175\ S/A - 0.0075\ S/A.\ V_{ca}$ | 0.98 | 1.4 |
| | %/min | $\Delta K(t)(0\text{-}t_c) = 0.16 - 0.00625\ \phi + 0.0044\ S/A + 0.0006\ V_{ca}$ | 0.88 | 4.6 |
| $t_c$ | min | $t_c = 587.7 - 48.56\ V_{ca} + 38.06\ \phi + 24.19\ S/A + 9.9375\ \phi.S/A$ | 0.98 | 5.5 |



## Contour diagrams

$K_{0@H=4m}$ (%)






## Conclusions

Field studies validate importance of thixotropy on form pressure characteristics. SCC of high thixotropy can exhibit :

- lower initial lateral pressure
- faster drop in pressure with time

**Formwork pressure of SCC = *f* (shear strength properties)**

1) Increased **internal friction** ⇒ Maximum initial pressure

(higher aggregate volume, lower binder content and w/cm, use of SCM, lower consistency level, ...)

2) Higher **cohesion** ⇒ Faster rate of pressure drop with time

(higher binder content, use of SCM and set-accelerator, lower HRWRA, higher temperature, lower consistency level, ...)