Robustness of SCC Incorporating Different Viscosity-Enhancing Admixtures

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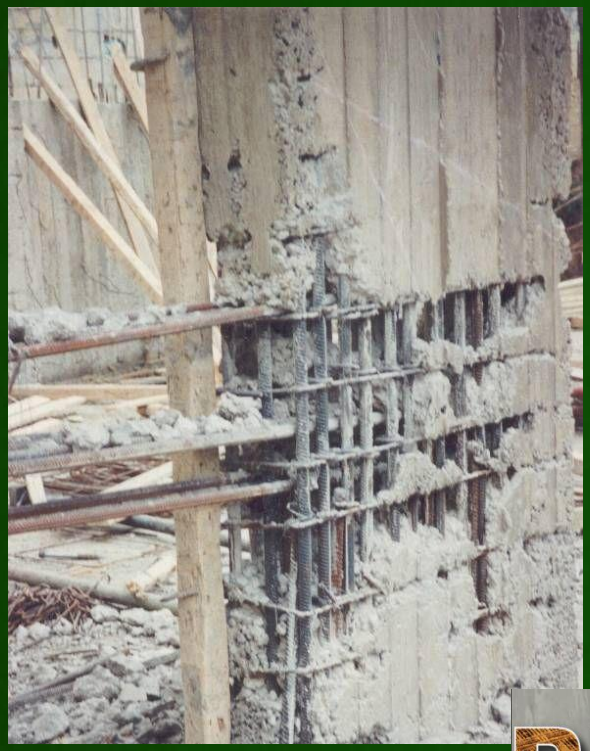

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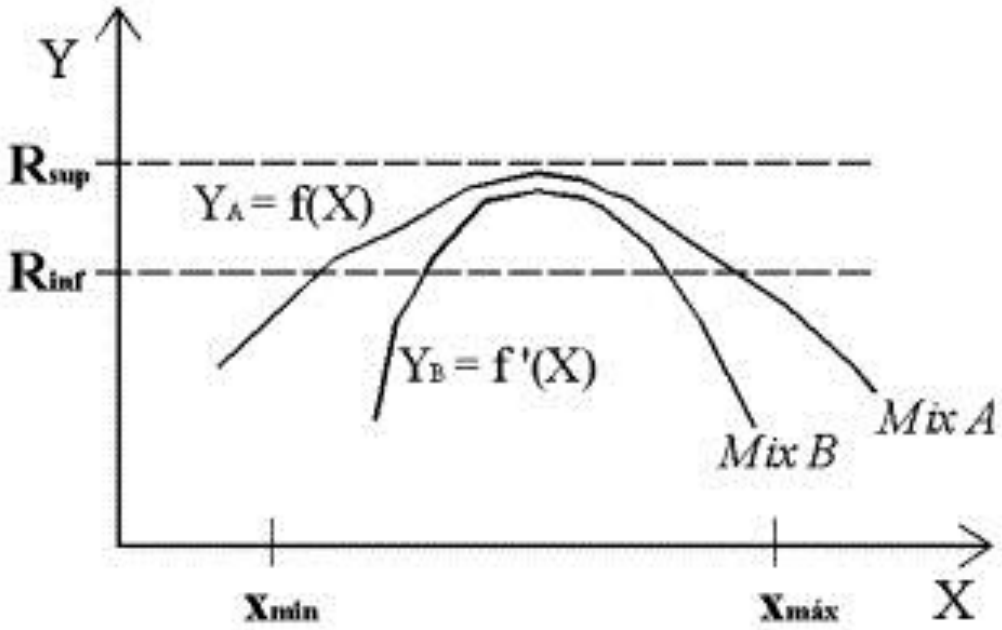
RE-CAST

Introduction

Robustness of concrete is defined as capacity of the material to tolerate certain variations in material characteristics and mixture parameters



Robust concrete (Mix A) has lower sensitivity to a given variaiton

Sand moisture content and SP dosage are considered as major parameters affecting robustness of SCC

Objectives

1. Evaluate effect of SP-VEA combinations on robustness of SCC subjected to small variations in sand humidity and SP dosage
2. Propose methodology to evaluate robustness
3. Identify test methods suitable for robustness evaluation

5 Types of VEAs

Codification	Type	Maximum apparent diameter
PS1	Anionic polysaccharide (Diutan gum)	180 µm (coarser grind)
PS2		75 µm (finer grind)
PS3	Anionic polysaccharide (Welan gum)	180 µm
CEL	Cellulose-based	< 210 µm
MS	Modified starch	-

Reference SCC mixture

SSD condition (kg/m^3)	
w/c	0.37
Type GU cement	470
Water	175
Coarse agg. (MSA 14 mm)	900
Sand	870
PNS	≈ 6 L/m^3
PCE	≈ 3 L/m^3
VEA (mass of water)	0.02% - 0.05%

8 SP-VEA combinassions:
PNS and PCE
5 VEA types

SP	VEA type	VEA dosage (%)
PNS	-	-
	PS1	0.02
	PS2	0.03
	PS3	0.03
PCE	-	-
	PS1	0.02
	CEL	0.05
	MS	0.03

Testing program

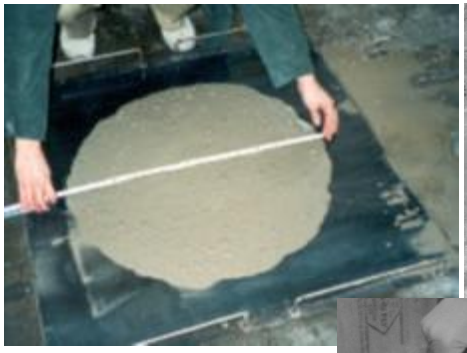
	SP	Variation (*w/cm*)	VEA
Phase I: Variation in sand humidity slump flow of 630 ± 20 mm	PNS (12 SCC)	SSD (0.37) SSD – 1% (0.35) SSD + 1% (0.39)	Control PS1 PS2 PS3
	PCE (12 SCC)	SSD (0.37) SSD – 1% (0.35) SSD + 1% (0.39)	Control PS1 CEL MS
Phase II: Variation in SP dosage	PNS (3 SCC)	SSS (0.37), -10%, 0, +10% SP	Selected VEA
	PCE (3 SCC)	SSS (0.37), -10%, 0, +10% SP	Selected VEA

Concrete property	
Fresh	Hardened
Slump flow (10-45 min) T-50 (10-45 min) VSI (10-45 min) Air content (10-45 min) Unit weight (10-45 min) J-Ring (10-45 min) Settlement Rheology Portable vane Inclined plane Slump flow with cylinder	Compressive strength at 7, 28, and 56 d Flexural strength at 56 d

Test methods

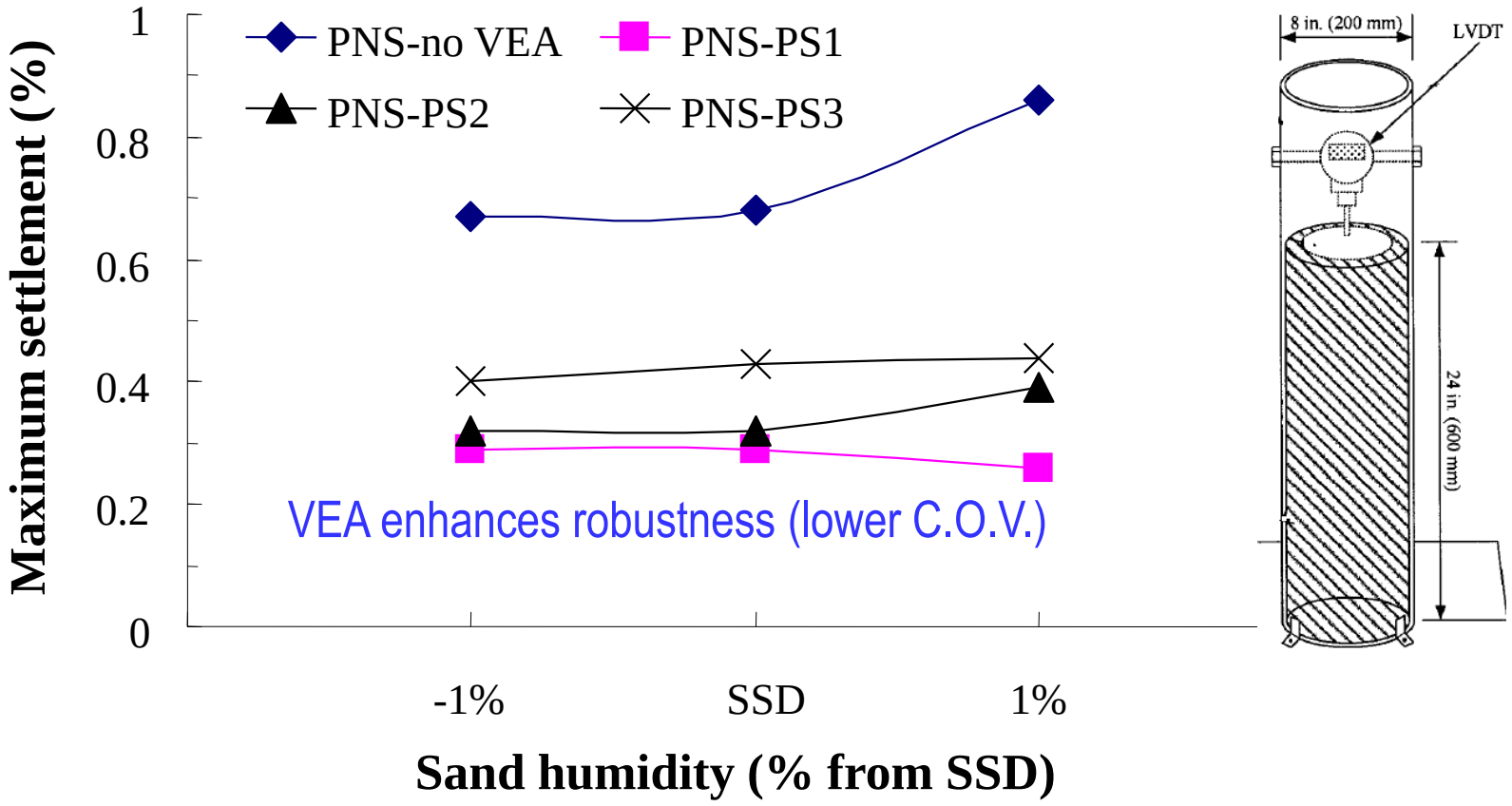
20 properties

1. 7-d fc'
2. 28-d fc'
3. 56-d fc'
4. 56-d fr
5. Vair at 10 min
6. T-50 at 10 min
7. J-Ring at 10 min
8. Cylinder slump flow 25 min
9. ΔVair
10. Slump flow – J-Ring at 10 min
11. ΔCylinder slump flow
12. Settlement
13. τ_0 @ 10 min
14. μ_p @ 10 min
15. $\tau_{0\ rest}$ (MK III) @ 25 min
16. τ_0 @ 70 min
17. μ_p @ 70 min
18. $\tau_{0\ rest}$ (MK III) @ 70 min
19. $\tau_{0\ rest}$ (PV) @ 25 min
20. Rate of structural buildup (PV)



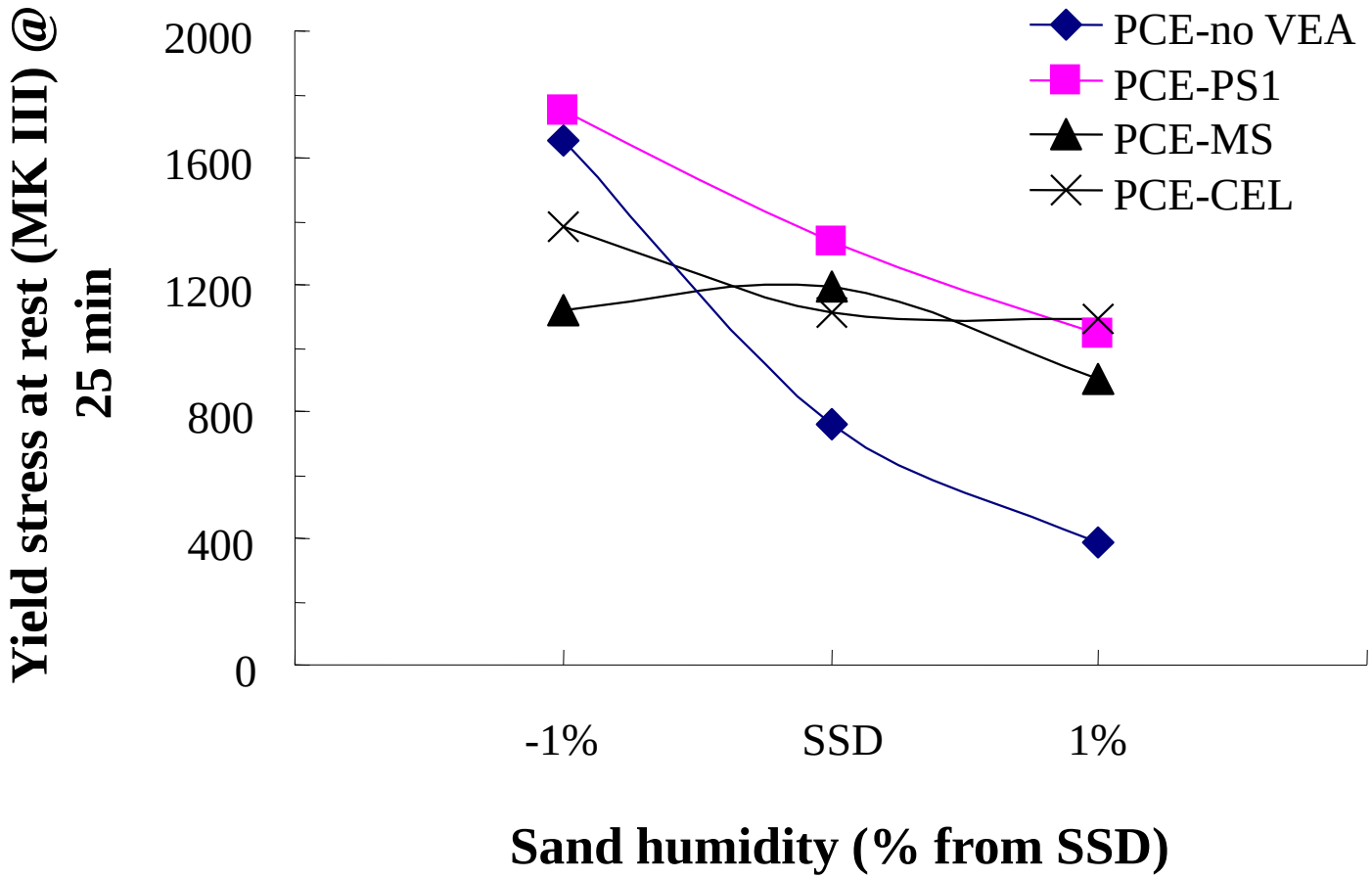
Effect of sand humidity on surface settlement

PNS SP



Effect of sand humidity on yield stress at rest

PCE-no VEA mixture exhibited higher sensitivity to variations of yield stress at rest to with changes in sand humidity



Robustness ranking using C.O.V. approach

Variation in rheological properties		PNS				PCE			
		No VEA	PS1	PS2	PS3	No VEA	PS1	CEL	MS
τ_0 @ 10 min	C.O.V.	38.4	9.2	4.3	14.0	8.4	19.5	29.8	24.0
	Rank	8	3	1	4	2	5	7	6
μ_p @ 10 min	C.O.V.	50.7	65.5	36.6	10.3	32.4	32.7	37.5	44.4
	Rank	7	8	4	1	2	3	5	6
$\tau_{0\ rest}$ (MK III) @ 25 min	C.O.V.	43.0	35.7	7.1	19.1	70.0	25.7	13.5	14.1
	Rank	7	6	1	4	8	5	2	3
τ_0 @ 70 min	C.O.V.	9.3	25.2	24.6	54.0	6.2	14.7	23.0	10.0
	Rank	2	7	6	8	1	4	5	3

Robustness ranking using C.O.V. approach

Lower C.O.V. → more robust → higher ranking

Variation in workability		PNS				PCE			
		No VEA	PS1	PS2	PS3	No VEA	PS1	CEL	MS
Air content (Vair)	C.O.V.	35.5	3.5	13.6	21.6	17.3	5.6	24.2	25.1
	Rank	8	1	3	5	4	2	6	7
T-50	C.O.V.	11.8	66.9	69.8	16.7	40.8	39.9	44.7	30.7
	Rank	1	7	8	2	5	4	6	3
J-Ring	C.O.V.	4.3	6.9	0	5.5	3.9	8.8	4.8	3.0
	Rank	4	7	1	6	3	8	5	2
Cylinder slump flow	C.O.V.	5.5	9.4	13.4	15.8	48.6	7.7	7.8	10.3
	Rank	1	4	6	7	8	2	3	5

Robustness ranking using C.O.V. approach

Variation in workability		PNS				PCE			
		No VEA	PS1	PS2	PS3	No VEA	PS1	CEL	MS
ΔVair	C.O.V.	84.6	15.8	70.5	60.3	94.4	43.3	33.3	96.1
	Rank	6	1	5	4	7	3	2	8
Slump flow – J-Ring	C.O.V.	32.5	33.3	0	37.5	20.0	54.0	25.6	13.1
	Rank	5	6	1	7	3	8	4	2
ΔCylinder slump flow	C.O.V.	33.3	15.8	35.7	26.2	55.3	12.5	12.5	17.6
	Rank	6	3	7	5	8	2	1	4
Settlement	C.O.V.	14.5	6.2	5.6	4.9	6.4	7.7	14.4	7.8
	Rank	8	3	2	1	4	5	7	6

Robustness ranking (20 properties)

Variation in mechanical properties		PNS				PCE			
		No VEA	PS1	PS2	PS3	No VEA	PS1	CEL	MS
7-d fc'	C.O.V.	3.1	6.2	3.5	6.5	9.8	7.0	9.2	6.0
	Rank	1	4	2	5	8	6	7	3
28-d fc'	C.O.V.	5.0	4.8	2.6	5.9	7.8	6.4	9.0	5.3
	Rank	3	2	1	5	7	6	8	4
56-d fc'	C.O.V.	5.3	5.6	6.9	5.7	7.9	3.6	7.0	6.0
	Rank	2	3	6	4	8	1	7	5
56-d fr	C.O.V.	7.3	7.7	6.1	6.0	8.2	3.6	7.4	4.7
	Rank	5	7	4	3	8	1	6	2

Ranking and classification of robustness to changes in sand humidity

SP-VEA	Sum of ranks, SR_i	Robustness Ranking	Normalized sum of ranks*
PNS-PS2 (DG-75)	27	1	100%
PNS-PS3 (WG-180)	38	2	75%
PNS-PS1 (DG-180)	40	3	71%
PCE-PS1 (DG-180)	42	4	66%
PCE-MS	48	5	52%
PNS	62	6	21%
PCE-CEL	68	7	7%
PCE	71	8	0%

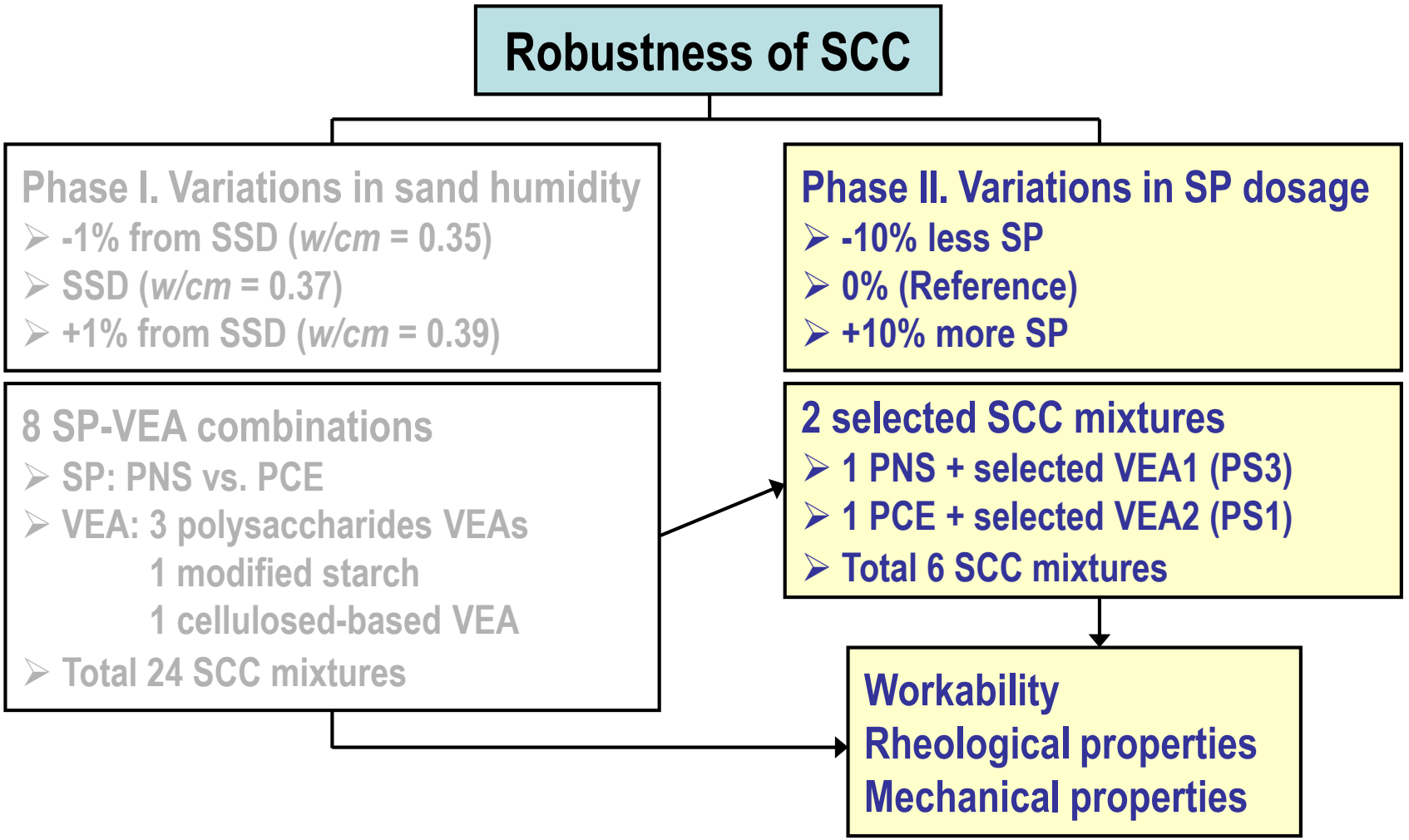
Normalized sum of ranks (%)

= 100 x (Max. SR – SR_i) / (Max. SR – Min. SR)

Ranking and classification of robustness to sand humidity

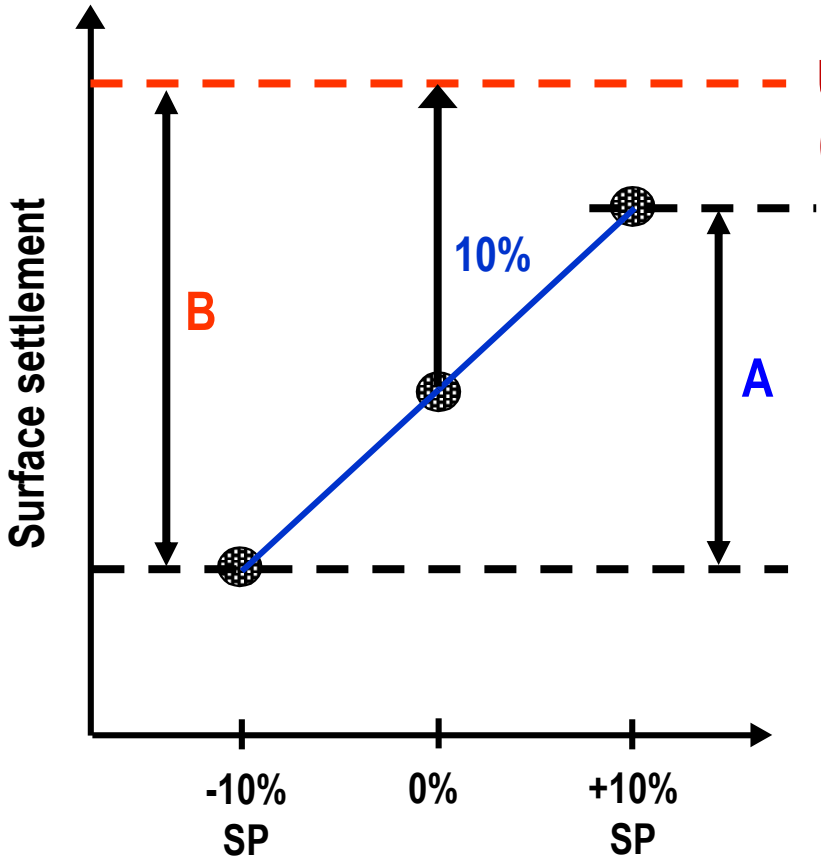
Normalized sum of ranks (%)	Category	Robustness	VEA
81 – 100	Category I	Very high	PNS-PS2 (DG-75)
61 – 80	Category II	High	PNS-PS3 (WG-180) PNS-PS1 (DG-180) PCE-PS1 (DG-180)
31 – 60	Category III	Medium	PCE-MS
≤ 30	Category IV	Low	PCE-CEL PNS-No VEA PCE-No VEA

Phase II - Variation in SP dosage



Deviation from targeted limit value

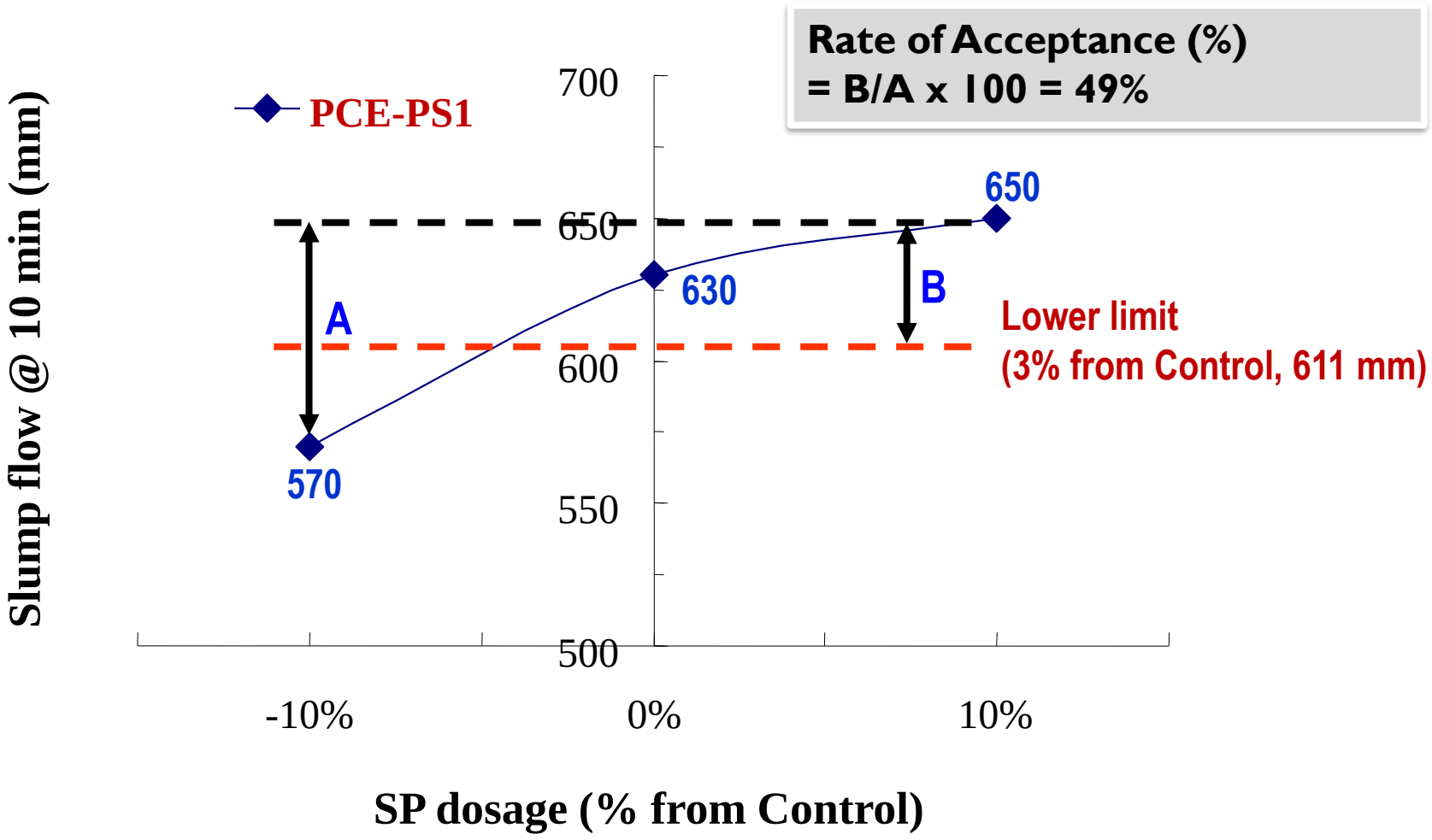
Variation limit for settlement = 10%



Rate of Acceptance (%)
= B/A x 100

Higher rate of acceptance
=> More robust

Slump flow


Rate of Acceptance (%)
= B/A x 100 = 49%
PCE-PS1
700
650
600
550
500
650
630
570
A
B
Lower limit
(3% from Control, 611 mm)
-10%
0%
10%
Slump flow @ 10 min (mm)
SP dosage (% from Control)

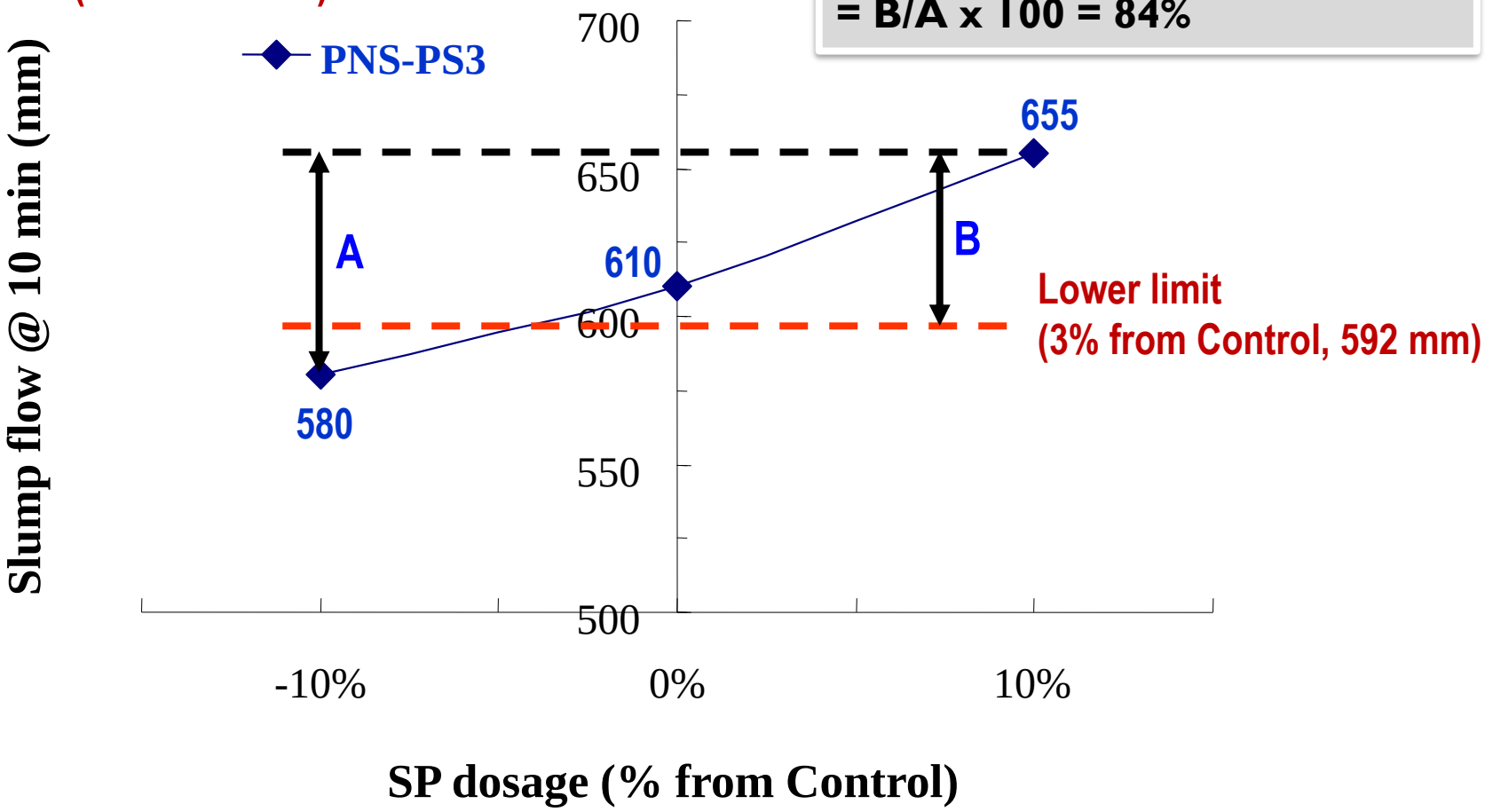
2 SCC mixtures for Phase II (variation in SP dosage)

	Variation limit from Control for each property	Upper or lower
7-d fc'	- 5%	Lower limit
28-d fc'		
56-d fc'		
56-d fr		
Slump flow at 10 min	- 3%	
J-Ring at 10 min	- 4%	
Settlement	+ 10%	Upper limit
T-50 at 10 min	+ 25%	
$\tau_{0\ rest}$ (MK III) @ 25 min	+ 5%	
$\tau_{0\ rest}$ (IP) @ 25 min		
$\tau_{0\ rest}$ (MK III) @ 70 min		

Slump flow

PNS-PS3 is more robust than PCE-PS1
(84% vs. 49%)

Rate of Acceptance (%)
= B/A x 100 = 84%



Rate of acceptance values

Phase II	Rate of Acceptance (%)	
	PNS-PS3 (WG-180)	PCE-PS1 (DG-180)
7-d fc’	81	100
28-d fc’	68	100
56-d fc’	101	100
56-d fr	55	100
Slump flow at 10 min	84	49
J-Ring at 10 min	60	100
Settlement	100	75
T-50 at 10 min	38	72
$\tau_{0\ rest}$ (MK III) @ 25 min	100	100
$\tau_{0\ rest}$ (IP) @ 25 min	100	37
$\tau_{0\ rest}$ (MK III) @ 70 min	100	17
Mean	80.6	77.3

Robustness (Phase I vs. Phase II)

Phase II	Rate of acceptance (%)	
	PNS-PS3	PCE-PS1
7-d fc'	81	100
28-d fc'	68	100
56-d fc'	101	100
56-d fr	55	100
Slump flow at 10 min	84	49
J-Ring at 10 min	60	100
Settlement	100	75
T-50 at 10 min	38	72
$\tau_{0\ rest}$ (MK III) @ 25 min	100	100
$\tau_{0\ rest}$ (IP) @ 25 min	100	37
$\tau_{0\ rest}$ (MK III) @ 70 min	100	17
Mean	80.6	77.3

≈

(Phase I) C.O.V.	Normalized sum of ranks (%)
PNS-PS2	100
PNS-PS3	75
PNS-PS1	71
PCE-PS1	66
PCE-MS	52
PNS	21
PCE-CEL	7
PCE	0

Objectives

1. Evaluate effect of SP-VEA combinations on robustness of SCC subjected to small variations in sand humidity and SP dosage
2. Propose methodology to evaluate robustness
3. **Identify test methods suitable for robustness evaluation**

Properties selected for robustness evaluation

20 properties

1. 7-d fc'
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19. $\tau_{0\ rest}$ (PV) @ 25 min
20. Rate of structural buildup (PV)

Kendall's Coefficient of Concordance

Spearman's Rank Correlation

11 properties

1. 7-d fc'
2. 28-d fc'
3. 56-d fc'
4. 56-d fr
5. Air content (Vair) at 10 min
6. Settlement
7. τ_0 @ 10 min
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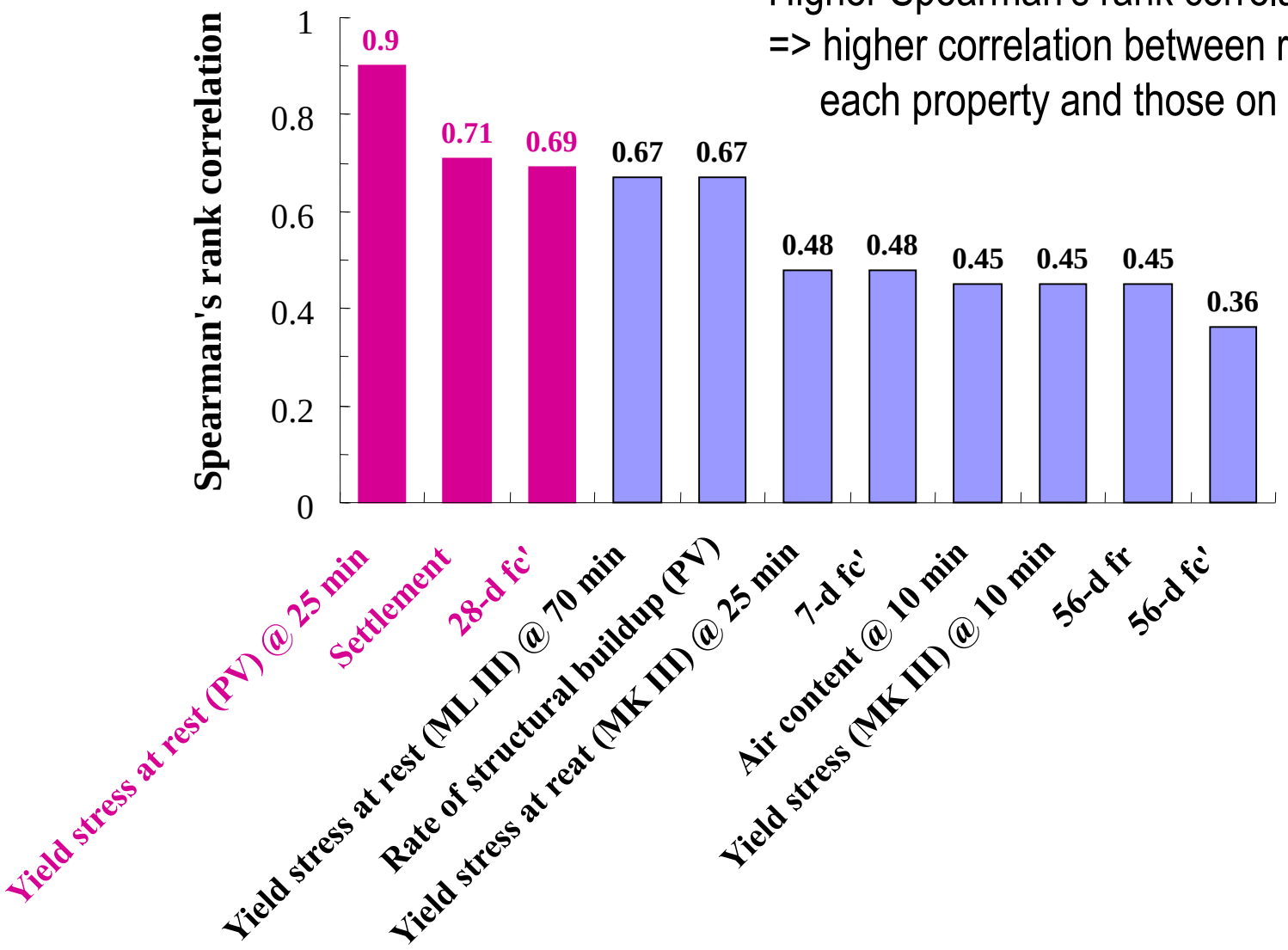
11. Rate of structural buildup (PV)

Robustness of SCC Incorporating Different Viscosity-Enhancing Admixtures, ACI Materials Jr, **108** (4), 2011, pp. 432-438.

11 Properties for Robustness Evaluation

Higher Spearman's rank correlation
=> higher correlation between ranks based on each property and those on all properties



Properties selected for robustness evaluation

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Kendall's Coefficient of Concordance

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Conclusions

- SCC made with PNS was more robust than that with PCE
- Incorporation of VEA enhanced robustness
- SCC made with polysaccharide VEAs were more robust than those with modified starch or cellulosed-based VEA
- COV or rate of acceptance can be used to evaluate robustness
- Statistical approach based on Kendall's coefficient of concordance and Spearman's rank correlation was used to identify key properties to assess robustness of SCC: 11 vs. 20 properties
- Min. testing program to evaluate robustness should include:
  - Yield stress at rest (concrete rheometer or portable vane)
  - Surface settlement
  - Compressive strength at 28 days