Performance Criteria for Self-Consolidating Concrete

Annual Concrete Seminar 2007

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28 February 2007

Problems Encountered

- Present situation
  - Multi-layer of reinforcing bars
  - High density of reinforcement
  - Small clearance between reinforcing bars
  - Complex formwork shape
  - Quality of compaction highly dependent on skill of workers
- Consequences
  - Difficulties in compaction
  - Strength and durability problems
- Solution
  - Use of self-consolidating concrete (SCC)

Properties of SCC

- High workability
  - Able to deform and flow just by its own weight
- High filling ability
  - Able to fill up confined spaces and far-reaching corners
- High passing ability
  - Able to pass through small clearances between closely spaced reinforcing bars
- High segregation stability
  - Able to remain homogeneous after flowing, dropping and passing through obstacles

Real Projects Employing SCC

- Akashi-Kaikyo Bridge
  - 240,000 m^3 of SCC was used for the two bridge anchorages
  - Concrete was pumped through 200 m and dropped up to 3 m without segregation
  - Construction time was shortened from 2.5 to 2 years
- A LNG tank in Japan
  - Number of lifts was reduced from 14 to 10 in casting a 38.4 m high wall
  - Number of workers was reduced from 150 to 50
  - Construction period was shortened from 22 to 18 months

Performance Attributes of SCC

Workability

- Two measures of workability
  - Deformability: ability to deform
  - Flowability: ability to flow
- Low- to medium-workability concrete: deformability is a better measurement of workability
- High-workability concrete: Flowability is a better measurement of workability
- Factors affecting workability
  - Water content
  - Superplasticizer dosage

Filling Ability

- Ability of the concrete to squeeze through narrow gaps and channels under the hydrostatic pressure of its own weight to fill up confined spaces and far-reaching corners
- Usually measured in terms of filling height
- Factors affecting filling ability
  - Workability
  - Cohesiveness
  - Aggregate proportion

Passing Ability

- Ability of the concrete to pass through small clearances between closely spaced reinforcing bars
- Usually measured in terms of reduced flowability of the concrete after installing a set of closely spaced reinforcing bars
- Factors affecting passing ability
  - Workability
  - Cohesiveness
  - Maximum aggregate size
  - Coarse aggregate content

Segregation Stability

- Ability of the concrete to resist segregation to remain homogeneous after flowing, dropping and passing through obstacles
- Usually measured by placing the concrete onto a porous tray and measuring the amount of paste and mortar dripping through the pores of the tray
- Factor affecting segregation stability
  - Cohesiveness

Test Methods and Acceptance Criteria

Test method for SCC

- Slump flow test
  - Workability
- V-funnel test
  - Workability
- U-box test
  - Filling ability and passing ability
- J-ring test
  - Passing ability
- Sieve segregation test
  - Segregation stability

Slump Flow Test

- Similar to the slump test for conventional concrete
- Apparatus
  - Slump cone
  - Flat, smooth and level steel base plate
- Procedure
  - Concrete is filled into the slump cone without tamping and trowel flat the top surface
  - Lift the slump cone steadily to allow the concrete to flow and deform

Slump Flow Test

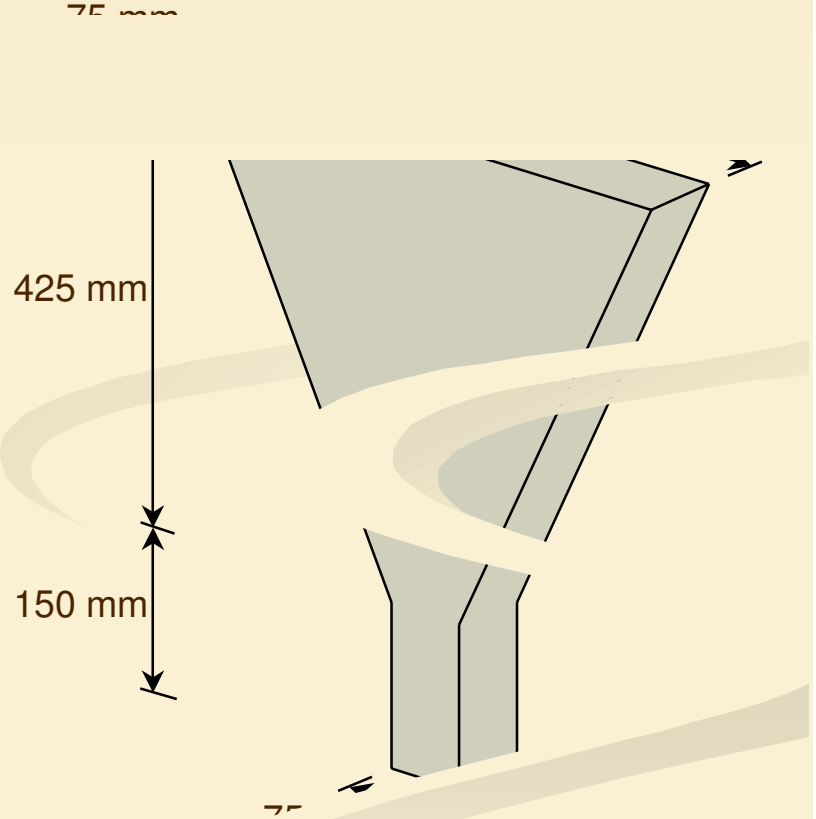
- Measured values
  - Slump: drop in height of the concrete
  - Slump flow: diameter of the concrete patty
- Slump flow test is NOT the same as the flow test stipulated in BS 1881: Part 105: 1984
  - Not suitable for SCC

Slump Flow Test

- Slump flow grades
  - SF1: Flow 550 - 650 mm
  - SF2: Flow 650 - 750 mm
  - SF3: Flow 750 - 850 mm
- Recommendation
  - Flow $\geqq$ 650 mm to ensure full self-consolidation

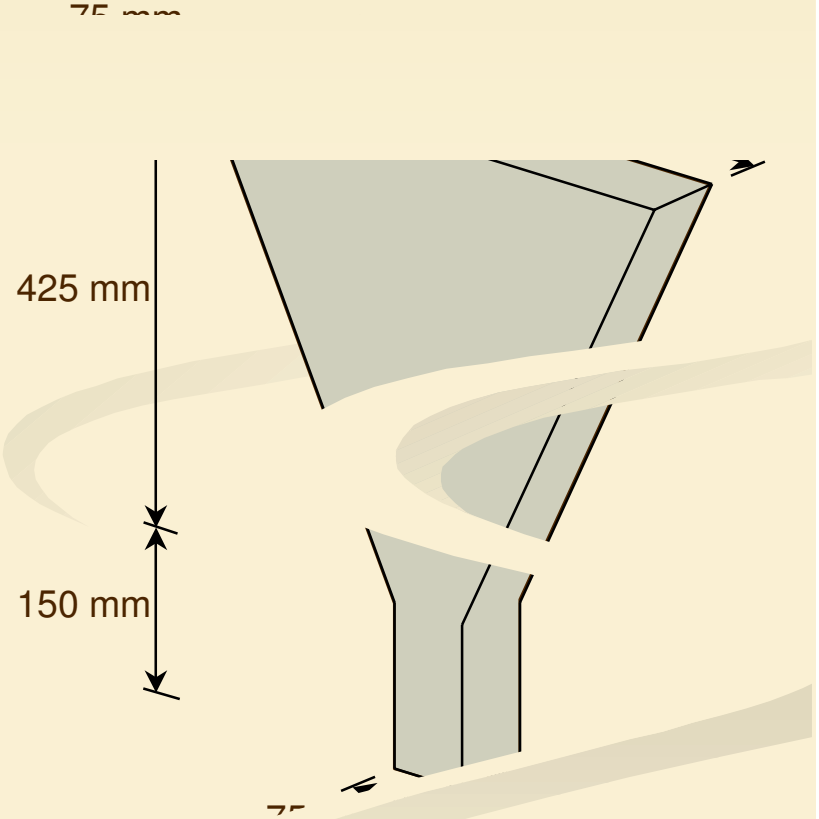
V-funnel Test

- Apparatus
  - V-funnel
- Procedure
  - Fill the concrete gently into the V-funnel until it reaches the top edge
  - Open the bottom lid to discharge the concrete

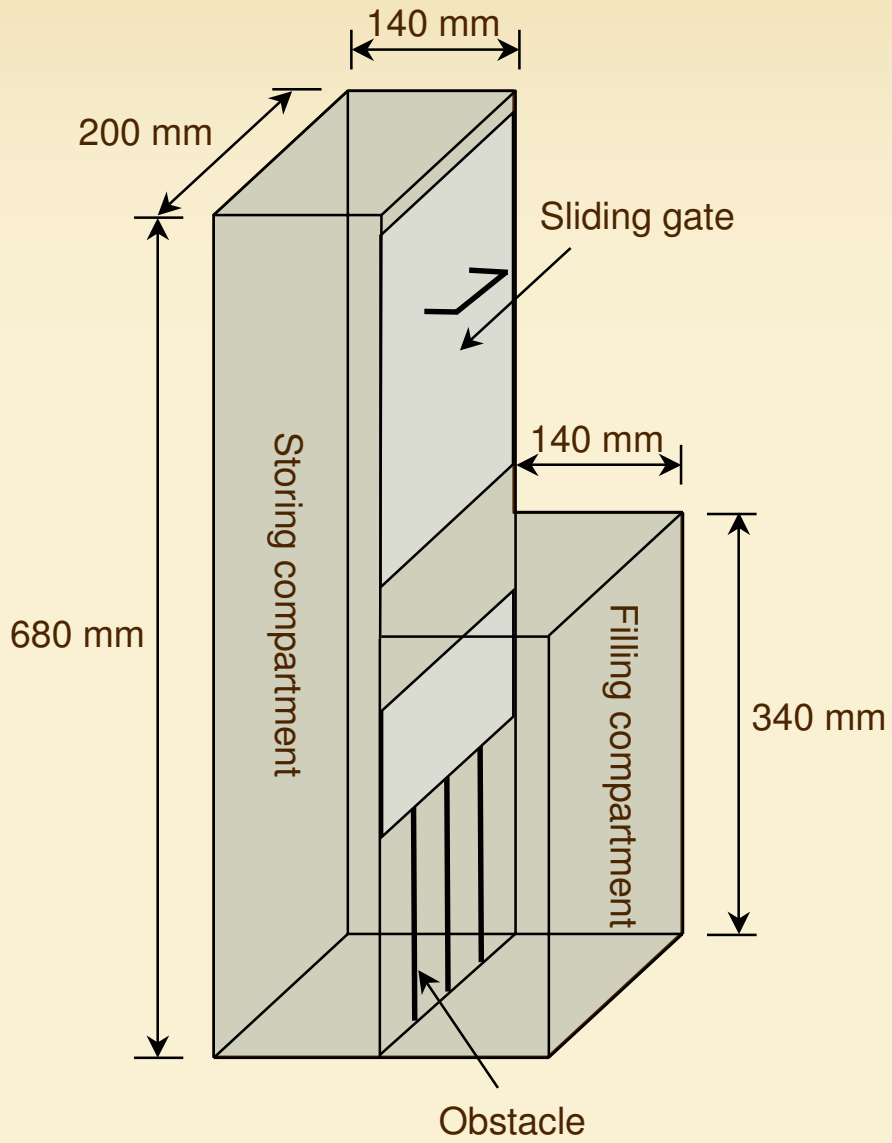


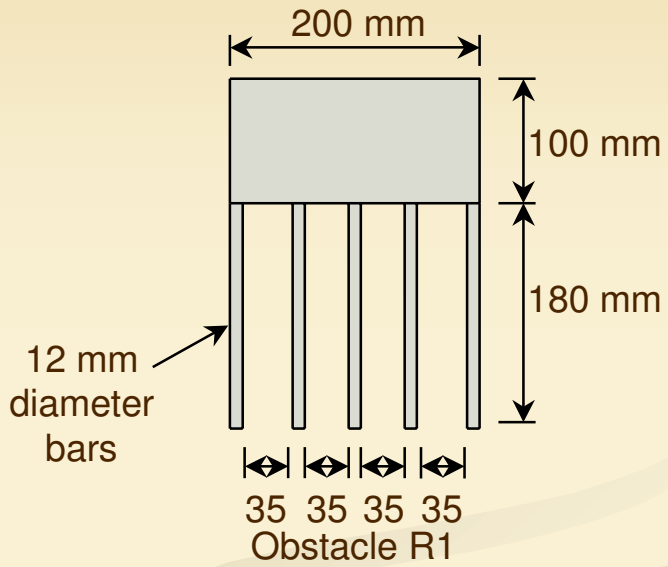
V-funnel Test

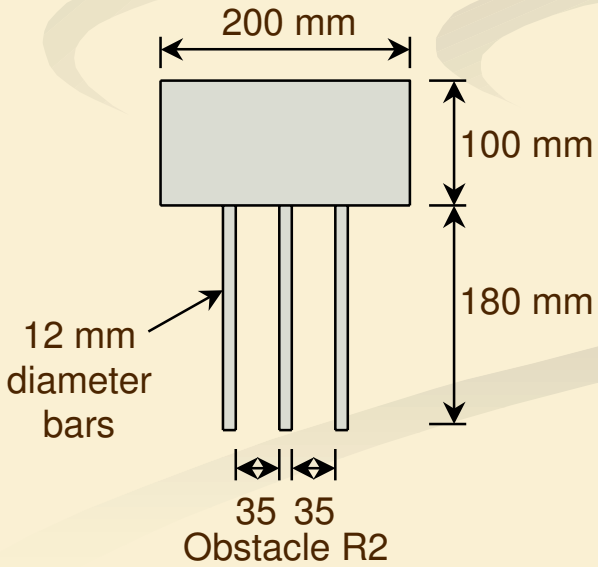
- Measured value
  - V-funnel time: The period between the time when the bottom lid is opened and the time that light can be seen through the orifice
- Acceptance criteria
  - V-funnel time $\leqq$15 seconds



U-box Test


140 mm
200 mm
Sliding gate
140 mm
680 mm
Storing compartment
Filling compartment
340 mm
Obstacle


200 mm
100 mm
180 mm
12 mm
diameter
bars
35 35 35 35
Obstacle R1


200 mm
100 mm
180 mm
12 mm
diameter
bars
35 35
Obstacle R2

U-box Test

- Apparatus
  - U-box
- Procedure
  - Close the sliding gate separating the storing compartment and filling compartment
  - Fill the concrete gently into the storing compartment
  - Open the sliding gate sharply to allow concrete to flow to the filling compartment
- Measured value
  - Filling height: the height of concrete filled in the filling compartment

U-box Test

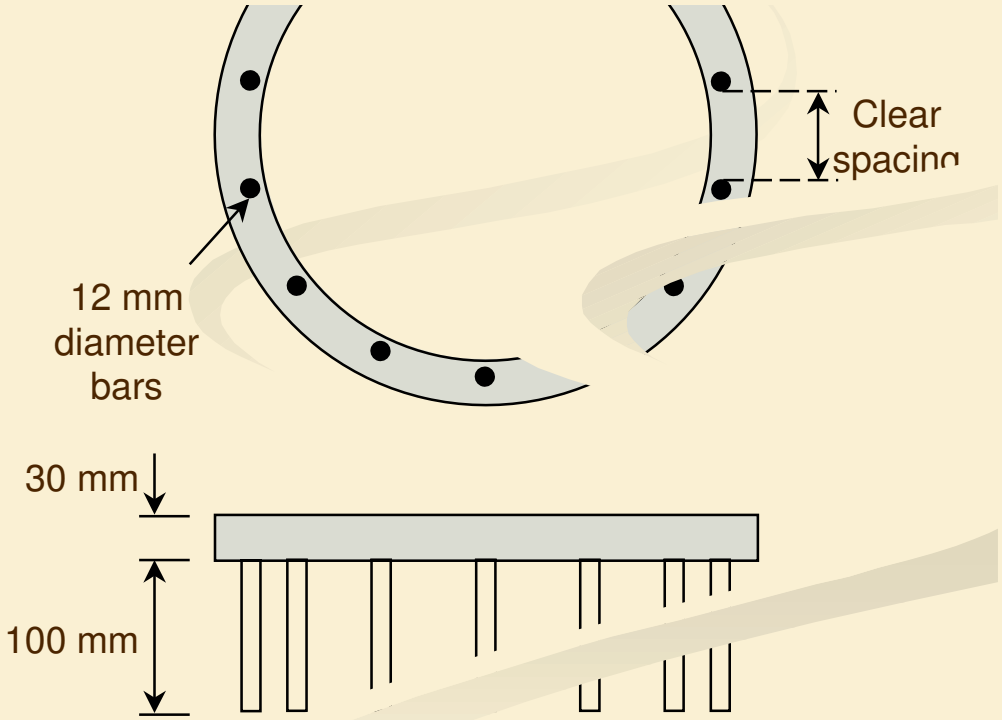
- Ranks of SCC for U-box test

Rank 1	Minimum clearance of 35 to 60 mm	Obstacle R1
Rank 2	Minimum clearance of 60 to 200 mm	Obstacle R2
Rank 3	Minimum clearance of larger than 200 mm	No obstacle

- Acceptance criteria
  - Filling height $\geqq$ 300 mm regardless of obstacle arrangement

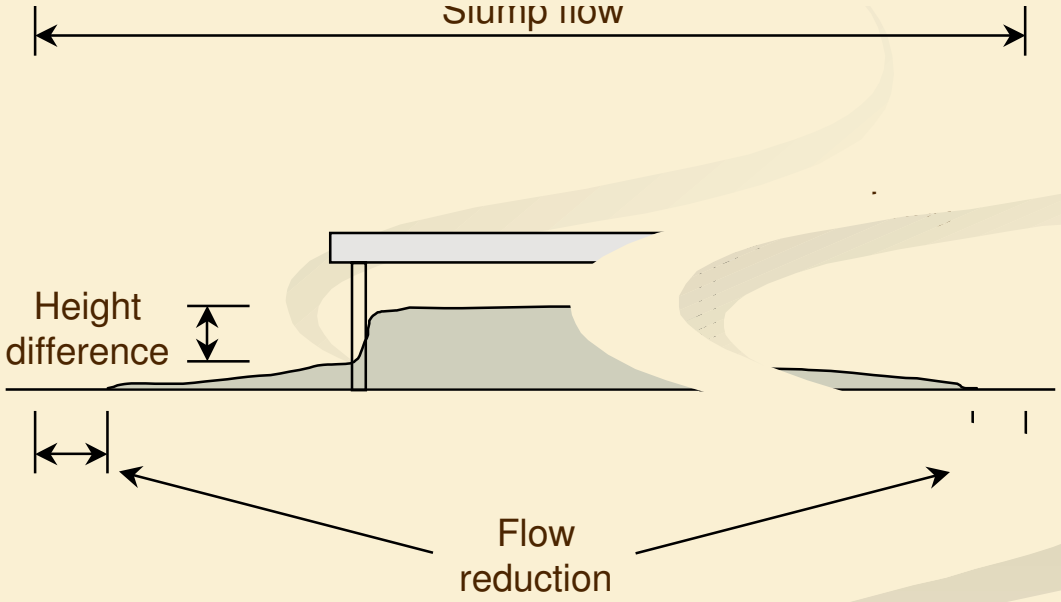
J-ring Test

- Apparatus
  - J-ring
  - Slump cone
  - Flat, smooth and level steel base plate
- Procedure
  - J-ring is placed outside the slump cone concentrically
  - Fill the concrete and lift the slump cone as in the slump flow test



J-ring Test

- Measured values
  - Flow reduction
  - Height difference
- Acceptance criteria
  - Flow reduction
    $\leqq$100 mm
  - Height difference
    $\leqq$ 20 mm

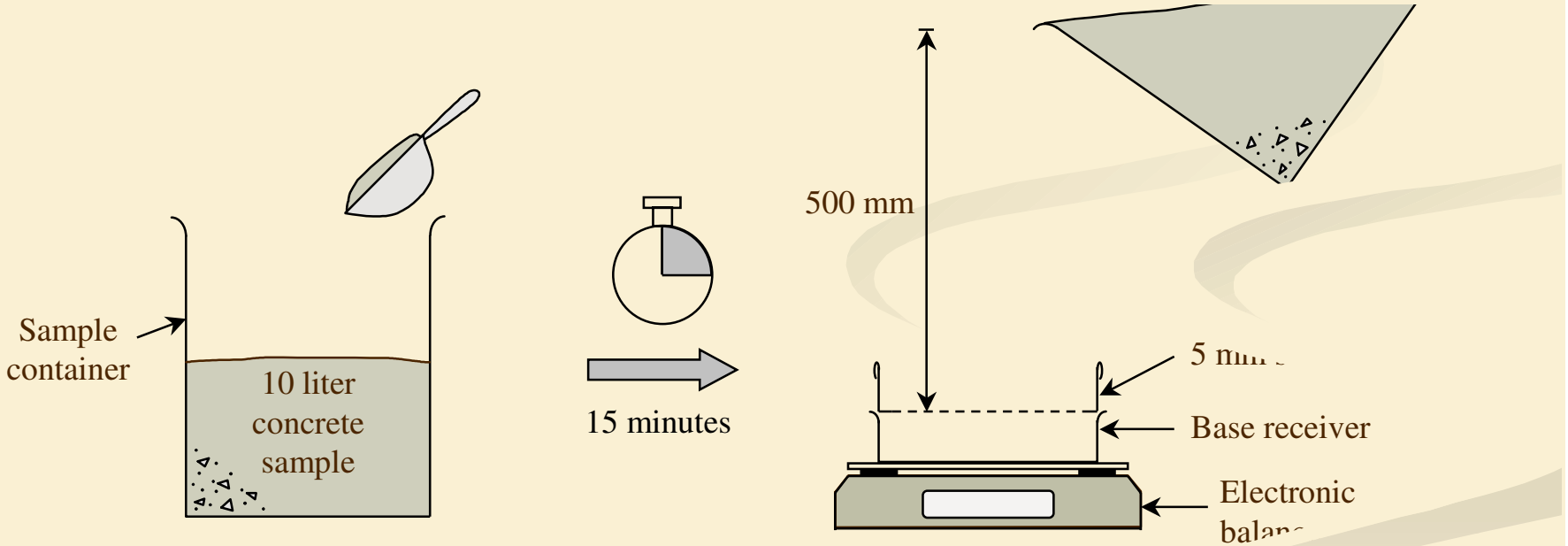


Sieve Segregation Test

- Two versions of sieve segregation test
  - Without allowing aggregate sedimentation to take place
  - Allowing aggregate sedimentation to take place
- Apparatus
  - 300 mm diameter sample container
  - 5 mm aperture test sieve
  - Base receiver
  - Electronic balance
  - Stop watch

Sieve Segregation Test

- Procedure



Sieve Segregation Test

- Measured value
  - Segregation index

$$\text{Segregatio n index} = \frac{W_p}{W_c} \times 100\%$$

W_p = Weight of material collected in the base receiver

W_c = Weight of concrete poured onto the sieve

- Classification and acceptance criteria

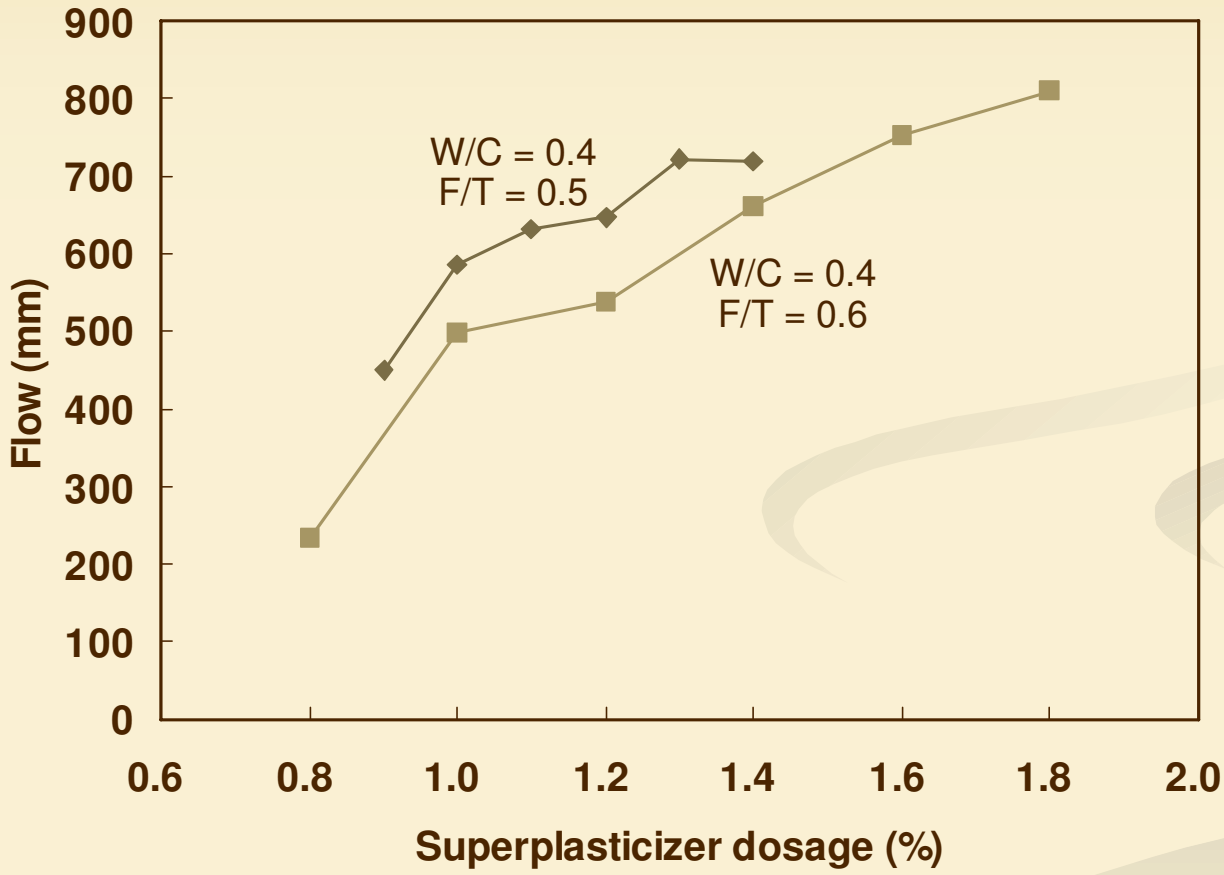
Segregation stability grade	Confinement gap width	Allowable segregation index
SS1	≧80mm	≦ 20%
SS2	< 80 mm	≦ 15%

Classification of SCC

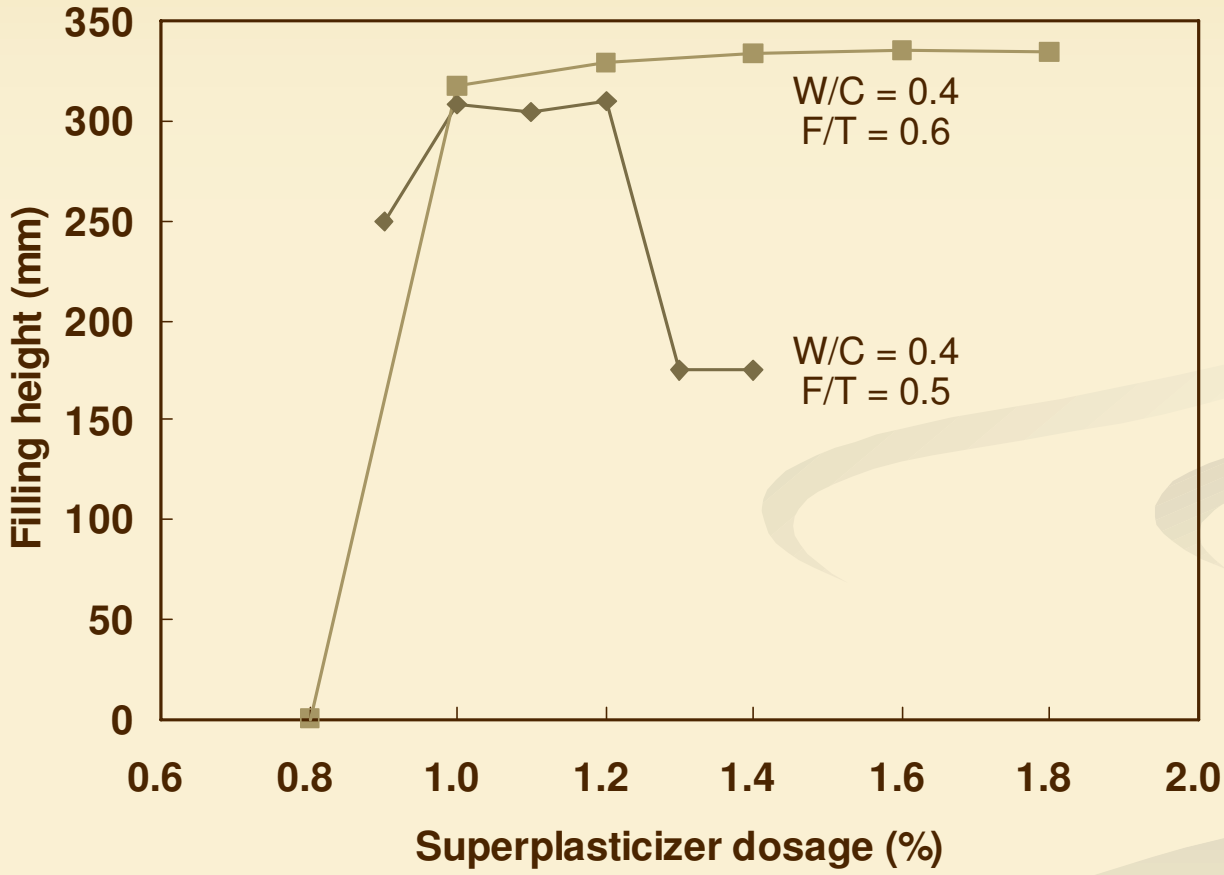
Test method	Performance criteria	
	High-flow SCC	**Super-high-flow SCC**
Slump flow test	Flow $\geqq$ 650 mm	Flow $\geqq$ 750 mm
V-funnel test	V-funnel time $\leqq$ 15 sec	V-funnel time $\leqq$ 8 sec
U-box test	Filling height $\geqq$ 300 mm (measured using obstacle R2)	Filling height $\geqq$ 300 mm (measured using obstacle R1)
J-ring test	Reduction in flow $\leqq$ 100 mm Height difference $\leqq$ 20 mm (measured using J-ring with bar clearance of 60 mm)	Reduction in flow $\leqq$ 100 mm Height difference $\leqq$ 20 mm (measured using J-ring with bar clearance of 40 mm)
Sieve segregation test	Segregation index $\leqq$ 20%	Segregation index $\leqq$ 15%

Laboratory Study in HKU

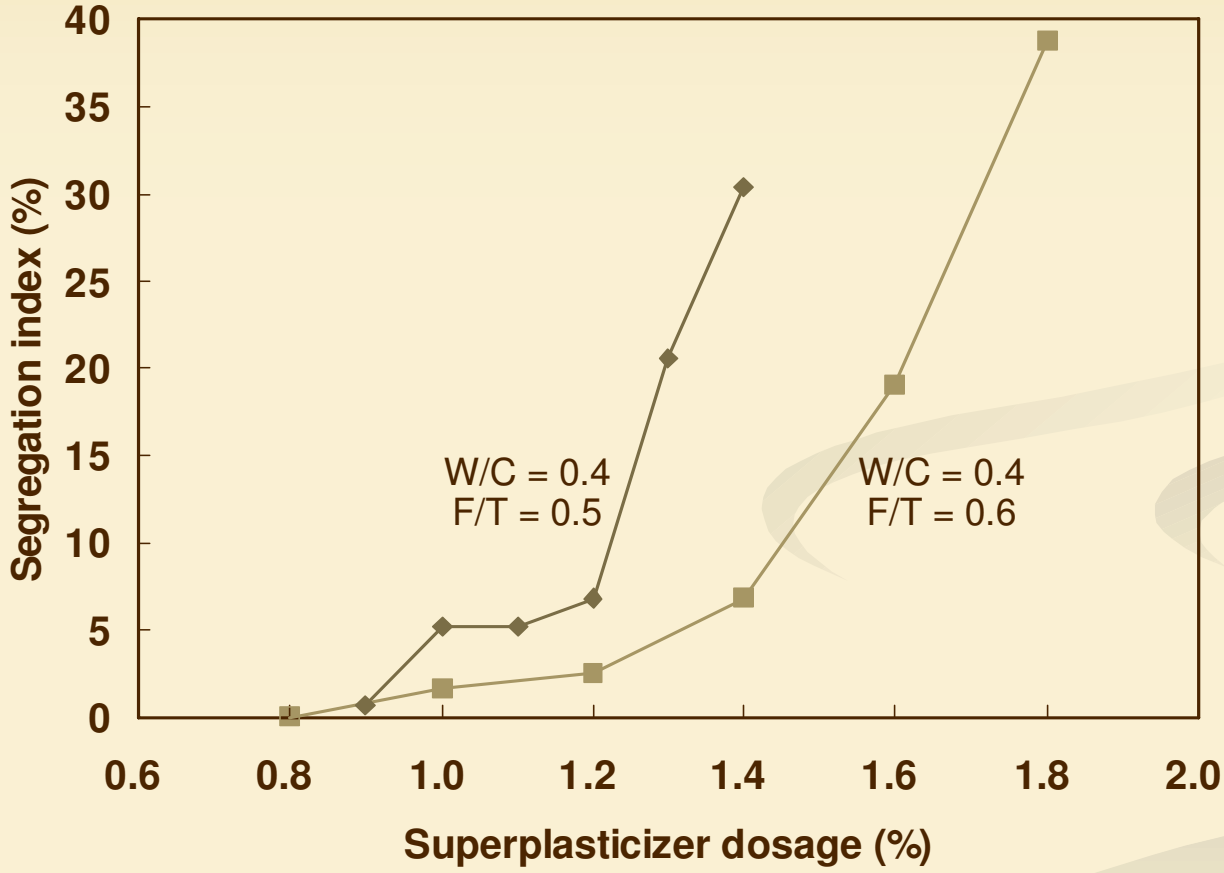
Slump Flow Test Results



U-box Test Results



Sieve Segregation Test Results



Conclusions

- SCC is more than a high-workability concrete
  - Filling ability
  - Passing ability
  - Segregation stability
- Test methods for SCC and corresponding acceptance criteria are presented
- Two grades of SCC are proposed
  - High-flow SCC
  - Super-high-flow SCC
- Government, concrete practitioners and academic should work together to develop SCC

Thank You