Self-Consolidating Concrete Construction for Modular Units

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Jurie van Wyk
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1. **Intro**

Objectives and outcomes

- Development of a self-consolidating concrete mixtures so that concrete placement can be made into steel plate composite (SC) modular structures without the need for continuous concrete placement.

  *Task 1: Development of SCC with Shear-Friction Capacity for Mass Placement*

- SCC mixtures to ensure sufficient shear capacity across cold-joints (self-roughening), while minimizing shrinkage and temperature increase during curing to enhance concrete bonding with the steel plates.

  *Task 1: Development of SCC with Shear-Friction Capacity for Mass Placement*
  *Task 2: Assessment of Cold Joint Shear-Friction Capacity*

- SCC mixtures featuring a self-roughening capability to produce adequate shear friction between cold joints and to produce draft provisions addressing shear-friction, for consideration in the AISC N690-12 Appendix N9 code used for the design of SC modular structures.

  *Task 2: Assessment of Cold Joint Shear-Friction Capacity*
  *Task 3: Assessment of Shear and Flexural Performance*
  *Task 4: Validation through Full-Scale Testing and Modeling*
  *Task 5: Draft Code Requirement for Shear Friction Design of Cold Joints*
1. Intro
Objectives

- Development of a self-consolidating concrete mixtures so that concrete placement can be made into steel plate composite (SC) modular structures without the need for continuous concrete placement.
1. Intro

Objectives
2. Development of SRC Mix Design Strategies

<table>
<thead>
<tr>
<th>Mix Component</th>
<th>67M</th>
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<td>Cementitious (lb/yd(^3))</td>
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<tr>
<td>Cement Type II</td>
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<th>Coarse Aggregates (lb/yd(^3))</th>
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<td># 89</td>
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<td>Total Coarse</td>
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<table>
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<th>Fine Aggregates (lb/yd(^3))</th>
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<td>Natural sand</td>
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<th>Admixtures (fl oz./cwt)</th>
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<td>HRWR</td>
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<td>TOT</td>
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- Smaller aggregates and controlled gradation curve
- Use of #67 and #89 coarse aggregates
- Substitute 5%, 10% and 15% in volume of coarse aggregate with LWA
Development of a Self-Roughening (SR) Concrete

2. Development of SRC Mix Design

Proprieties and tests

- **Flowability**: flows easily at suitable speed into formwork (T20 = 4-5 sec; Flow Slump = 24-26”)
- **S Groove test**: (good self-healing ability)
- **Hardened Visual Stability Index (VSI)** = 0

**Fresh SCC proprieties**

**Hardened SRC proprieties**

- **Compressive strength**: 6-7 ksi
- **Shrinkage**: <250 με
2. Development of SRC Mix Design
Measurements of Roughness
2. Development of SRC Mix Design Roughness

ICRI’s CSPs
2. Development of SRC Mix Design

Roughness
2. Development of SRC Mix Design
Measurements of Roughness

ACI 318-11 (11.6.9): “...when concrete is placed against previously hardened concrete, the interface for shear transfer shall be clean and free of laitance. If $\mu$ is assumed equal to $1.0\lambda$, interface shall be roughened to a full amplitude of approximately $1/4$ in.”
3. Assessment of Cold Joint Shear Friction Capacity

Mechanical tests for shear friction characterization

Laboratory test
3. Assessment of Cold Joint Shear Friction Capacity

Mechanical tests for shear friction characterization

- **Step 1**: Initial setup of the test apparatus.
- **Step 2**: Adding concrete mixture to test the friction.
- **Step 3**: Inserting reinforcement before casting.
- **Step 4**: Formation of the concrete joint.
- **Step 5**: Final stage of the test, ready for evaluation.
3. Assessment of Cold Joint Shear Friction Capacity

Mechanical tests for shear friction characterization

Knife-edge support
LVDT
LVDT support
Knife-edge support
200kip load cell
3. Assessment of Cold Joint Shear Friction Capacity

Failure modes

- Internal Reinforcement: $\rho = 0.75\%$

- External Steel Plate: $\rho = 0.25\%$
  $t = 0.031$ in. (22 gage)

- External Steel Plate: $\rho = 0.50\%$
  $t = 0.063$ in. (16 gage)

- External Steel Plate: $\rho = 0.75\%$
  $t = 0.094$ in. (13 gage)

- External Steel Strips: $\rho = 0.75\%$
  $t = 0.375$ in.
3. Assessment of Cold Joint Shear Friction Capacity

Test Results – Internal versus External Reinforcement

![Graph showing load slip relationship for CJ0575-1 (Internal) and SP1550-1 (External).]
3. Assessment of Cold Joint Shear Friction Capacity

External Reinforcement – Effect of Reinforcement Ratio

![Graph showing load vs. slip for different reinforcement ratios. The graph includes three curves labeled SP1575, SP1550, and SP1525. SP1575 shows the highest slip at 0.61 inches, followed by SP1550 at 0.56 inches, with SP1525 having the lowest slip at 0.56 inches.]}
3. Assessment of Cold Joint Shear Friction Capacity
Test Results – External Plate versus Strip Reinforcement

![Graph showing load versus slip for SP1575 and ST1575]

- Load (kips)
- Slip (in.)
- SP1575
- ST1575
(a) Non-linear finite element model in LS-DYNA explicit. This initial model approximate the geometry of specimen SP 15 50-1 but with fewer Nelson studs.
Development of a Self-Roughening (SR) Concrete

- Effective point of fixity assuming flexural stiffness of stud without concrete confinement
- Theoretical point of stud fixity in concrete
- Local bending of steel plate
- Local crushing of concrete
- Gap

Graph:
- Stud Shear Resultant (kips) vs. Effective Stud Displacement (in.)
(b) Initial loading. Constant shear in the panel zone. In-plane shear stresses shown (all stresses in Pa).
(e) Buckling progresses. Steel plate begins to yield in the vicinity of two studs (see red on stress contour). Buckling distortion as the plate pulls away from the concrete visible.
Development of a Self-Roughening (SR) Concrete
4. Assessment of Shear and Flexural Performances
Specimens preparation

In-Plane Loading

Out-of-Plane Loading
Task 3
A. Control - No cold joint 1 in-plane and 1 out-of-plane

B. Out-of-Plane

C. In-Plane

Development of a Self-Roughening (SR) Concrete
Development of a Self-Roughening (SR) Concrete
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Development of a Self-Roughening (SR) Concrete
5. Validation through Full-scale Test and Modeling Model
6. Conclusions and Outlooks
And future developments

1. Task 2 test results demonstrate the ability of steel plate composite construction to transfer in-plane forces across the cold-joint boundaries.
2. Results show that SC construction is more ductile than conventional internally-reinforced concrete.
3. Test results show that self-roughening concrete with at least 5% LWA provides shear friction coefficient (λ) of 1.0 or greater.
4. The test results do not conclusively demonstrate the relationship between LWA percentage and cold-joint shear capacity.
5. Non-linear FEA models are promising and may be used for parametric studies of joint behavior – but further calibration is needed.
6. Task 3 specimens will validate in-plane shear behavior and provide better guidance on the out-of-plane behavior of cold-joint behavior in SCC.
7. The Task 4 specimen will be a tremendous challenge and we are working closely with Westinghouse to procure the test article from CBI in a cost-effective and timely manner.
## Development of a Self-Roughening (SR) Concrete

### Task 1. Developed SCC Mixes

1. Rheology of SCC Mixes
2. Shear Friction Evaluation Across SCC Roughened Cold Joins

### Task 2. Measurment of Cold-Joint Effects in Flexure and Shear

### Task 3. Upscaling: Experimental assessments of shear friction, pressure, shrinkage/delamination, and strength

### Task 5. Model Development

### Task 5. Shear Friction Provisions

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**Timeline**

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<th>2015</th>
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Thank you. Questions?