Analysis and Design Issues in Liquid-Containing Concrete Structures

ACI Fall 2012 Convention
October 21 – 24, Toronto, ON

CRACK CONTROL IN TWO-WAY REINFORCED CONCRETE PANELS

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OUTLINE
- Research Significance and Scope
- Proposed Crack Prediction Model
- Experimental Program
- Verification
- Design Guide
- Conclusions
- Acknowledgements

SIGNIFICANCE OF CRACK CONTROL
- Serviceability: Deflection control, Leakage control, ...
- Durability: Permeability reduction, Corrosion reduction, ...
- Appearance

SHORTCOMINGS OF CURRENT DESIGN CODES
- Simple loading conditions: Pure bending, pure tension, ...
- No reliable crack control for two-way members
- Ignoring repeated loading effects
- Ignoring long term effects

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**SCOPE OF RESEARCH**

- Experimentally investigating the cracking and leakage behaviour of two-way panels
- Using FE technique to understand different aspects of RC cracking
- Developing a new analytical crack prediction model for two-way panels

**TWO-WAY ELEMENTS**

**PROPOSED CRACK PREDICTION ANALYTICAL MODELS**

**STABILIZED CRACKING LOAD**

\[ N_{cr} = \left( f_{ce} - \beta_{SP} \sigma_{SP} - \sigma_{ct} \right) A_{cr} \left( 1 + \alpha \rho_{ct} \right) \]

**MINIMUM CRACK SPACING**

\[ S_{min}^{II} = \left( d_{cr} - d_{m} \right) \left( f_{ce} - \beta_{SP} \sigma_{SP} - \sigma_{ct} \right) \]

**MAXIMUM CRACK SPACING**

\[ S_{max}^{II} = \text{larger of} \left\{ \frac{s_{cr} + S_{min}^{II}}{2}, S_{max}^{II} \right\} \]

**MAXIMUM CRACK WIDTH AT STABILIZED CRACKING**

\[ w_{max} = \beta_{SP} S_{max}^{II} \left( f_{ct} - \epsilon_{ct} - \epsilon_{m} \right) \]

**STABILIZED CRACKING**

- Diagram illustrating the stabilized cracking load and behavior.
MECHANISM OF BOND

Concrete Elements
Steel Elements
Link Elements

Concrete Node
Steel Node

-1.5
-1
-0.5
0
0.5
1

Displacement ()

Concrete Tensile Stress ()

Crack Opening Displacement ()

BOND LAYER MODEL

Section A-A

Strain Gauge

Transverse Circular Hole for Anchorage

VERIFICATION OF BOND MODELS

KANKAM TEST

Steel Stress ()

Tammo Test

FE (Bond Layer)

LVDT (wsurf)

LVDT (w11)

TAMMO TEST

TAMMO Test

Metal Tube

Steel Plate

Tammo

GLUED PLATE + METAL TUBE
SPLITTING STRESSES

SHRINKAGE INDUCED TENSILE STRESSES

\[ N_{s} = (f_{s} \cdot (t) - \beta_{s} \cdot \sigma_{s} - \sigma_{s} \cdot \alpha_{s} \cdot \rho_{s}) \]

\[ \sigma_{s} = \frac{E_{s} \cdot \varepsilon_{s} - \sigma_{s}}{50 	imes 10^{6}} \]

\[ \sigma_{s} = 0.35 \cdot f_{s} \cdot \left( \frac{E_{s} \cdot \varepsilon_{s} - \sigma_{s}}{d_{c}} \right)^{1.5} \] (SI units)

AVERAGE SPLITTING STRESSES

\[ \sigma_{app} = f \left( f_{s} \cdot (t) - \beta_{s} \cdot \sigma_{s} - \sigma_{s} \right) \]

\[ \beta_{s} = \frac{2}{3} \cdot \frac{2 \cdot \sigma_{s}}{d_{c}} \]

EFFECTIVE TENSION AREA

\[ N_{t} = (f_{t} \cdot (d) - \beta_{t} \cdot \sigma_{t} - \sigma_{t} \cdot \alpha_{t} \cdot \rho_{t}) \]

**PARAMETRIC STUDY**
MINIMUM CRACK SPACING

\[ S_{\min} = \frac{(d_0 - d_p)\varphi}{\alpha_0 \beta_0 \sigma_0} (f_{\text{con}} - \sigma_{\text{m}}) \]

\[ S_{\max} = \frac{d_0 - d_p}{\alpha_p \beta_p \sigma_p} (f_{\text{con}} - \sigma_{\text{m}}) \]

\[ S_{\min} = \text{lesser of} \quad S_{\min} = 2S_{\max} \quad (\text{low probability}) \]

\[ S_{\max} = \text{larger of} \quad S_{\max} = 2S_{\max} \quad (\text{high probability}) \]

MAXIMUM CRACK WIDTH AT STABILIZED CRACKING

\[ W_{\text{max}} = \frac{2\alpha_0 \beta_0 \sigma_0 S_{\max}^{\text{II}}}{E_i d_1} (\varepsilon_0 - \varepsilon_{\text{cr}} - \varepsilon_0) \]

\[ \varepsilon_{\text{cr}} = \varepsilon_{\text{cr}} + \frac{1}{\beta} (1 + \alpha_x, \beta_{\text{off}}) \]

\[ \Delta \varepsilon_{\text{m}} = \frac{2\alpha_0 \beta_0 \sigma_0 S_{\max}^{\text{II}}}{E_i d_1} \]

REDUCTION OF BOND STRENGTH DUE TO SPLITTING CRACKS

BOND STRENGTH REDUCTION DUE TO LONGITUDINAL SPLITTING CRACKS
EXPERIMENTAL PROGRAM
LOADING SCHEME

SCHEMATIC OF TEST SETUP (PLAN-VIEW)

SCHEMATIC OF TEST SETUP (EAST-SIDE-VIEW)

SCHEMATIC OF TEST SETUP (SOUTH-SIDE-VIEW)

TEST SETUP

VERIFICATION

STABILIZED CRACKING LOAD

CRACK SPACING
CONCLUSIONS

- New crack prediction model in two-way RC panels that incorporates:
  - New FE parametric studies of:
    - Bond shear and normal stresses
    - Average splitting tensile stresses
    - New factor for effective tension area
    - Shrinkage induced tensile stresses
    - Bond strength reduction due to splitting cracks
- Better agreement with experimental results
- New accurate design guidelines to replace unconservative ACI design guideline

ACKNOWLEDGEMENTS

Financial support provided by
Natural Sciences and Engineering Research Council of Canada (NSERC)
Ryerson University
Candu Energy Inc.

THANK YOU
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